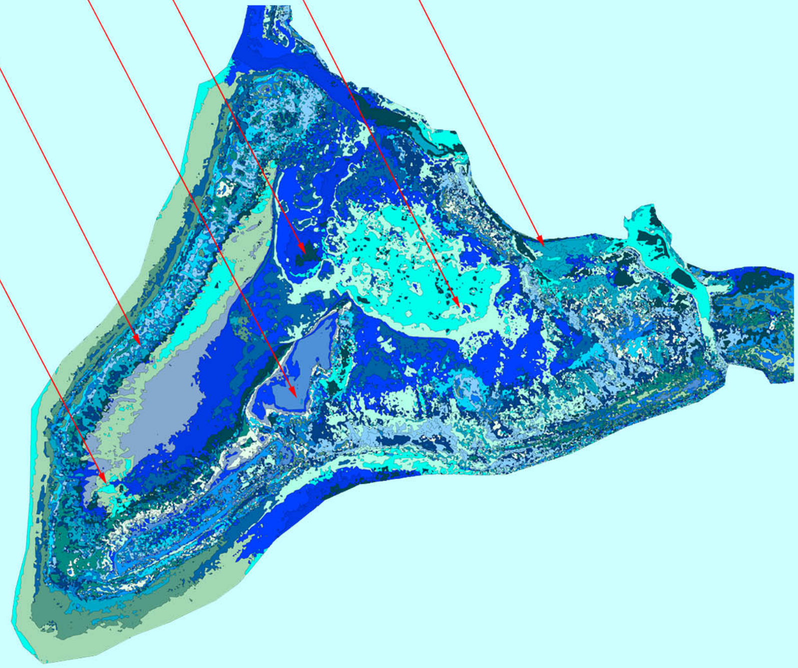
NOAA's National Ocean Service

Integrated Coral Reef Ecosystem
Mapping & Monitoring Products and Outcomes
March 2001

A Partnership Program Led by NOS's National Centers for Coastal Ocean Science In Cooperation with other NOAA Offices, Federal Agencies, States, Territories, Commonwealths, and Freely Associated States

Cocos Lagoon, Guam



NOAA'S NATIONAL OCEAN SERVICE
NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE
FY 00/01 INTEGRATIVE CORAL REEF RESEARCH PROGRAM
TO MAP, ASSESS, INVENTORY, & MONITOR
US CORAL REEF ECOSYSTEMS

ABOUT THIS BRIEFING BOOK

This collection of reports and products have been organized into this briefing book to provide the current status and plans within NOAA/NOS's National Centers for Coastal Ocean Science (NCCOS) coral reef research program to map, assess, inventory, and monitor US coral reef ecosystems. Although these coral reef activities have been lead and integrated by NCCOS, the products and ongoing research components would not be possible without the strong partnerships forged within NOS, NOAA, other Federal Agencies (e.g. DOI), States, Territories, and Commonwealths. The efforts of NOS's Special Projects Office, National Geodetic Survey, and the Coastal Services Center were essential to the successful implementation of the FY00 mapping initiative.

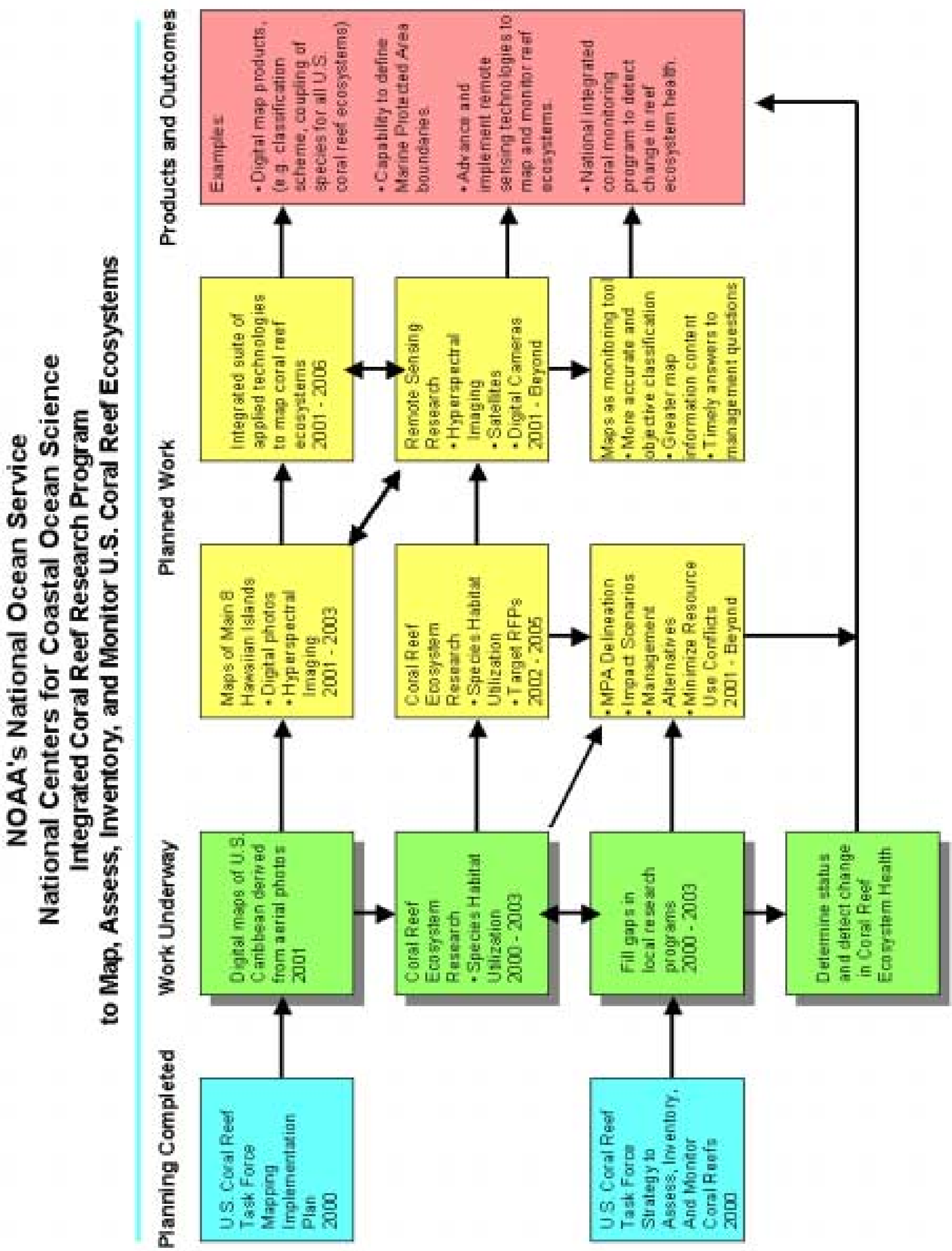
The joint activities between Federal agencies are particularly important to map, research, monitor, manage, and restore coral reef ecosystems. In response to the Executive Order, NOS is conducting research to digitally map biotic resources and coordinate a long-term monitoring program that can detect and predict change in US coral reefs and associated habitats. Most US coral reef resources have not been digitally mapped at a scale or resolution sufficient for assessment, monitoring and research to support resource management. Thus, a large portion of NCCOS's coral reef research activities have focused on mapping of US coral reef ecosystems and is the primary work highlighted in this briefing book. The map products will provide the fundamental spatial organizing framework to implement and integrate research programs and the capability to effectively communicate information and results to coral reef ecosystem managers.

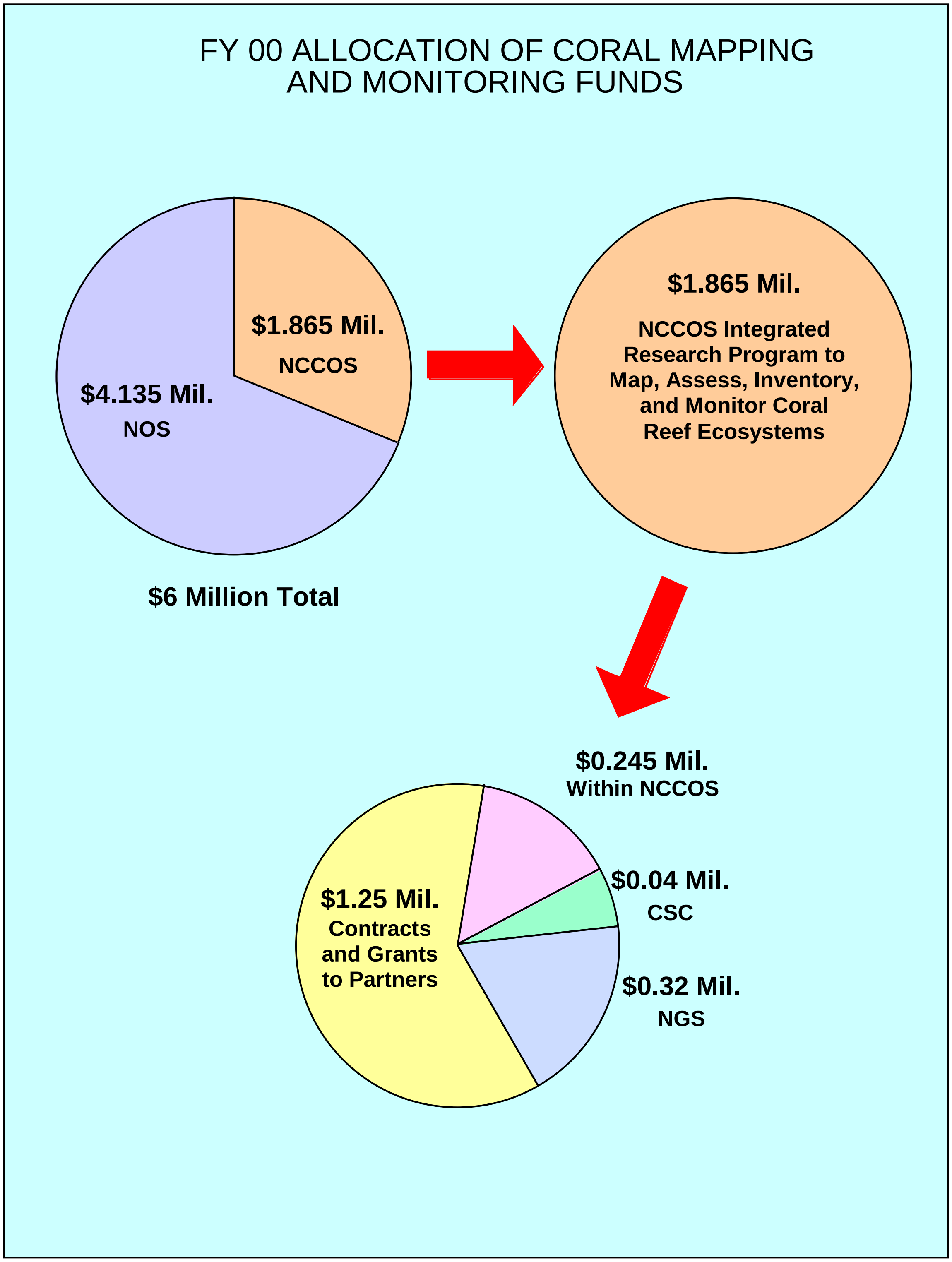
The research and associated products of NCCOS's coral reef activities have been developed over the past 12-18 months with about $2 million dollars of the $6 million that NOS received for coral activities in FY 00. Although the NOS/NCCOS coral program is relatively young, it has had tremendous success in advancing towards the goal to protect, conserve, and enhance the health of US coral reef ecosystems, as evidenced by the products and activities described in this book. To address this goal NCCOS has several operational objectives:

1) Design and implement an integrated program of coral reef research to enable development of products that support management needs and questions.
2) Determine the status of the distribution and health of coral reef ecosystems and be able to detect changes in reef integrity over time.
3) Define species habitat utilization patterns in space and time within coral reef ecosystems to support management needs and questions.
4) Organize and communicate research results from mapping and assessing, inventorying, and monitoring activities into a suite of products required for better protection, conservation, and enhancement of US coral reef ecosystems.

To meet our goals and objectives, NCCOS and its partners have developed an integrated program of research to develop management products in both the short-and-long-term (See Figure). For example, NOS has the capability to produce accurate and georeferenced coral reef ecosystem maps based on the current state of remote sensing technologies for mapping studies. However, the time to produce these types of products for management must be reduced to increase protection of rapidly deteriorating coral reef ecosystems. Thus, NCCOS has developed new methods using computer and remote sensing technologies to map products several times faster than previous coral mapping efforts. NCCOS will continue to invest in research to make maximum use of emerging technologies from satellite and aircraft remote sensing platforms to produce more accurate and scientifically defendable coral reef maps over shorter time-periods while reducing costs. In addition, NCCOS mapping studies have resulted in many additional advances in the development of management products. Examples include defining biologically relevant boundaries of Marine Protected Areas by conducting species habitat utilization studies using the recently developed coral reef ecosystem maps and delineation of water depths (bathymetry) derived from satellite technology. In FY 01/02 the integrated research program addressing habitat and species mapping, and assessing, inventorying, and monitoring of coral reef ecosystems will continue to develop products required by managers to protect, conserve, and enhance coral reefs.

Please continue to monitor the progress of this work on NOS/NCCOS's Biogeography Program website (http://biogeo.nos.noaa.gov).


NOAA's National Ocean Service
National Centers for Coastal Ocean Science
Integrated Coral Reef Research Program
to Map, Assess, Inventory, and Monitor U.S. Coral Reef Ecosystems
Planning Completed
Work Underway
Planned Work
Products and Outcomes
U.S. Coral Reef Task Force Mapping Implementation Plan 2000
U.S. Coral Reef Task Force Strategy to Assess, Inventory, And Monitor Coral Reefs 2000
Digital maps of U.S. Caribbean derived from aerial photos 2001
Coral Reef Ecosystem Research • Species Habitat Utilization 2000 - 2003
Fill gaps in local research programs 2000 - 2003
Determine status and detect change in Coral Reef Ecosystem Health
Maps of Main 8 Hawaiian Islands • Digital photos • Hyperspectral Imaging 2001 - 2003
Coral Reef Ecosystem Research • Species Habitat Utilization • Target RFPs 2002 - 2005
• MPA Delineation • Impact Scenarios • Management Alternatives • Minimize Resource Use Conflicts 2001 - Beyond
Integrated suite of applied technologies to map coral reef ecosystems 2001 - 2006
Remote Sensing Research • Hyperspectral Imaging • Satellites • Digital Cameras 2001 - Beyond
Maps as monitoring tool • More accurate and objective classification • Greater map information content • Timely answers to management questions
Examples:
• Digital map products, (e.g. classification scheme, coupling of species for all U.S. coral reef ecosystems)
• Capability to define Marine Protected Area boundaries.
• Advance and implement remote sensing technologies to map and monitor reef ecosystems.
• National integrated coral monitoring program to detect change in reef ecosystem health.


FY 00 ALLOCATION OF CORAL MAPPING AND MONITORING FUNDS
$1.865 Mil.
NCCOS
$4.135 Mil.
NOS
$6 Million Total
$1.865 Mil.
NCCOS Integrated Research Program to Map, Assess, Inventory, and Monitor Coral Reef Ecosystems
$0.245 Mil.
Within NCCOS
$0.04 Mil.
CSC
$0.32 Mil.
NGS
$1.25 Mil.
Contracts and Grants to Partners

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CORAL REEF MAPPING IMPLEMENTATION PLAN

MAPPING AND INFORMATION SYNTHESIS WORKING GROUP of the U.S. CORAL REEF TASK FORCE

Rose Atoll - American Samoa

This document should be cited as:
Coral Reef Mapping Implementation Plan (2nd Draft). November 1999. U.S. Coral Reef Task Force, Mapping and Information Synthesis Working Group. Washington, DC: NOAA, NASA and USGS (Work Group Co-chairs). 17 pp.

I. ABOUT THIS DOCUMENT

This document was produced to support the U.S. Coral Reef Task Force (CRTF), created by Executive Order P.L. 13089, which calls for the conservation and protection of the nation's coral reefs. The Mapping Implementation Plan (MIP) complements the CRTF's Mapping and Information Synthesis Working Group's (MISWG) mapping strategy document, which was presented and endorsed by the CRTF at its March 1999 meeting in Maui, Hawaii (MISWG 1999a). The Task Force requested that the Mapping Implementation Plan be completed by November 1999 to enable mapping efforts to move forward in 2000. The MIP provides the first comprehensive framework to map all U.S. coral reef habitats by 2007 using a suite of satellite, aircraft, and underwater data-collection platforms. The MIP is an evolving document that will be routinely revised and updated based on Working Group and user comments, funding constraints, and changes in technology. This document will be used as source material for the coral reef mapping section of the U.S. CRTF Action Plan.

II. BACKGROUND

U.S. Coral Reef Task Force and the Mapping and Information Synthesis Work Group

On June 11, 1998, President William Jefferson Clinton announced Executive Order 13089, "Coral Reef Protection," to conserve and protect U.S. coral reef ecosystems and those species, habitats and other natural resources associated with coral reefs in all maritime areas and zones subject to U.S. jurisdiction (i.e., federal, state, territorial and commonwealth waters). The Task Force's duties are organized around four thematic areas: (1) coral reef mapping and monitoring, (2) research, (3) conservation, mitigation, and restoration, and (4) international cooperation. To implement Executive Order 13089, several working groups were formed to address and develop action plans for each thematic area.

With respect to coral reef mapping, Executive Order 13089 directs the Task Force, in cooperation with state, territory, commonwealth, and local government partners, to coordinate a comprehensive program to map and monitor U.S. coral reefs. The National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and National Aeronautics and Space Administration (NASA) were designated as the federal co-chairs of the Mapping and Information Synthesis Working Group to lead the development of a comprehensive coral reef mapping plan. The Working Group's overall goal is to develop a strategy for creating a set of comprehensive, consistent U.S. and territory coral reef ecosystem maps and a map information synthesis capability. The Executive Order states that to the extent feasible, remote-sensing capabilities should be developed and applied to this effort, and that local communities should be encouraged to participate. In response to these guidelines, the Working Group has developed three primary documents to implement the coral reef mapping component of the Executive Order.

The first two documents, (1) A Strategy to Map State, Commonwealth, Territory, and Freely Associated State Coral Reef Ecosystems in the U.S. (MISWG 1999a), and (2) Summary of Issues and Proposed Actions. Report of the Mapping and Information Synthesis Working Group to the Coral Reef Task Force (MISWG 1999b), were presented at the second U.S. CRTF meeting in March 1999. The Task Force recommended that the Working Group's proposed strategy be adopted, and directed the Working Group to develop a companion document to implement comprehensive mapping of U.S. coral reef ecosystems. Depending on resource availability and mapping techniques selected, several additional documents will be required to outline specific protocols and procedures for data collection, data processing, digital map development, and institutional partnerships to conduct the work. Based on priorities presented in the MIP, these documents will be developed as mapping activities proceed forward.

This Mapping Implementation Plan reflects the feedback to the Strategy document, the summary report, and numerous Working Group meetings. A brief summary of these documents and meetings is provided below as background information fundamental to developing the plan. These documents and other background materials, as well as results from the first and second meetings of the Task Force, can be viewed on the Web at <http://coralreef.gov/>. In the working group's documents, we define mapping as determining the location and extent of benthic habitats, assessment as characterizing the health of benthic (e.g., coral) communities, and monitoring as the ability to detect and measure changes over time in benthic habitat communities. It is important to recognize that "mapping" has many components including development of digital shorelines, high resolution bathymetry, habitat classification systems, and digital habitat maps.

While our primary goal is to produce coral reef ecosystem maps, the working group fully recognizes the importance of merging these map products with other information. Information acquired through coral reef monitoring activities, some of which have been going on many years, needs to be incorporated. Because the coral reef maps will be developed and distributed in geographic information systems (GIS), incorporating these other types of information will create a "tool" that can be used by researchers and managers to study and evaluate the condition of the ecosystem. Data collected in the past can be compared to current conditions to measure change. Data from other sources, such as industrial discharge permits, land-based water quality monitoring activities, public health-related monitoring activities and others, can be integrated and looked at simultaneously. In addition, other thematic map layers, such as the land use activities, locations of industrial discharge pipes, water quality monitoring stations, river inputs of fresh water, navigation routes, and commercial and non-commercial marine species spatial distributions can be incorporated into the GIS. The result is a powerful, flexible decision support tool for coral reef ecosystem research, conservation, and management. For example, such a tool can be used to: develop better marine environmental education programs that stress the importance of coral reef ecosystems and their conservation; identify and evaluate areas where coral reef management efforts are needed immediately; characterize and evaluate the status of the essential habitat of commercial and non-commercial marine species; develop management strategies for marine protected areas; predict and model the potential damage to populated areas caused by severe weather; and support activities that evaluate and develop capabilities to conduct long-term monitoring and change analyses.

Summary of Working Group Issues and Actions

The initial Working Group meetings resulted in several key actions and identified important issues concerning coral reef mapping throughout the U.S., and it's territories, commonwealths, and freely associated states. The Working Group agreed to identify technologies that should be used to collect data and to recommend what type of digital coral reef maps (e.g., spatial resolution) should be developed based on input from scientists and local and regional coastal managers. This resulted in a multidisciplinary Working Group that included members from federal, state and local governments, academia, the private sector and private citizens (Appendix 1). A complete list of partner institutions can be found in MISWG (1999a).

The Working Group agreed that both short-term (1-5 years) and long-term (>5 years) coral reef mapping goals should be identified. The Working Group narrowed the definition of map information to that which can be incorporated into a geographic information system (GIS). Thus, maps should be digital, and information layers should be tied to a geographic base map. Although the mapping effort will focus on coral reefs, the Working Group recommends that associated shallow benthic (bottom) habitats, such as seagrass, sand, mangroves, and hard substrate, should also be mapped.

The first activity of the Working Group was to inventory existing hard-copy and digital coral reef map products for U.S. coral reef ecosystems. This activity is described in the section of the plan entitled "Mapping and Information Synthesis - Existing Data and Products," and in Appendix 2. A wide variety of data sources of varying content and quality were identified and compiled. These will be used to aid in the development and validation of upcoming digital coral reef map products. This will lead to discussions regarding the distribution of digital data.

The Working Group identified two high-priority issues: (1) the lack of digital maps of coral reefs, and (2) an inability to detect changes in coral reef distribution, health and ecology over time.

(1) Digital Maps

Baseline digital maps do not exist for all coral reef ecosystems within the United States and its territories. The lack of map information is particularly evident in the Pacific.

To address the need for a comprehensive set of baseline maps, the Working Group proposed in its mapping strategy the short-term goal of:

Producing comprehensive digital coral-reef ecosystem maps for all U.S. State and Territories within five – seven years, beginning in the Pacific where critical gaps presently exist.

The feature resolution of comprehensive digital coral reef maps will range from 1 sq. km (satellite technology) to 1 - 5 sq. m (aircraft; e.g., air photos) depending on available resources, local mapping requirements and available technology. The Working Group and the user community defined high-resolution maps as those that depict features less than or equal to 5 meters in size (features typically visible in aerial photography of 1:12,000 to 1:48,000 scale). This resolution is required for high-priority areas as defined by island and state partners. In addition, the Task Force recommended that the *Benthic Habitats of the Florida Keys* CD-ROM serve as a prototype for the type of research and management capability desired for other coral reef ecosystems (NOAA/FMRI 1998). While it may not be feasible to map all U.S. coral reefs (estimated to be 17,000 sq km) to this level of detail, the *Benthic Habitats of the Florida Keys* product was identified as a model for areas that require high-resolution maps. Where possible, very fine resolution data (e.g., <1 m), such as maps derived from scuba observations, should be integrated into the digital mapping framework. It is important to note that these digital maps will be developed using commercially-available software that simplifies the translation of data into numerous formats. In addition, the digital data will be made available as soon as possible via the Internet. Lastly, the data will be standardized to current horizontal and vertical datums.

(2) Detecting Change

The technology does not presently exist to routinely monitor change in coral reef ecosystems over time in an operational, cost-effective procedure. A distinction must be made between the role of remote sensing in producing a single, comprehensive map (baseline) of a coral reef at a given point in time, versus the role of remote sensing in long-term monitoring. The Working Group recommends routine updates to the Nation's benthic habitat maps across regional and local spatial scales. Thus, a second issue identified by the Working Group concerns the need to develop cost-effective methods of mapping reefs and of conducting long-term change analyses. Remote sensing technologies are rapidly advancing from the research and development mode to more applied coral reef mapping efforts. **However, *no region-wide* (e.g., the Caribbean), *high-resolution* coral reef maps have been produced using remote sensing technology (e.g., hyperspectral imaging), nor have long-term change analyses been conducted.**

To develop the technology to detect change, the long-term goal is to: *Develop, within 10 years, remote sensing technologies for routine, operational monitoring of coral reef ecosystems.*

In the near-term, remote sensing research and associated experiments to map coral reefs and other benthic habitats should lead to improved methods of acquiring and updating digital baseline maps. However, long-term monitoring requires the maintenance of stable, well-calibrated instruments, and analytical methods capable of distinguishing the variability of the reefs from variability in the water quality conditions present in the overlying water column. Therefore, based on the two concerns discussed above, applied and experimental remote sensing technologies should be used and advanced to meet the challenge of developing consistent and comprehensive digital coral reef ecosystem maps for the nation, as directed by the Task Force.

III. WHY REMOTE SENSING?

Remote sensing (e.g., aerial photography, satellite/airborne spectral imaging) of benthic habitats is the only option to obtain synoptic data for large coastal and island areas. This provides a view that is not possible from *in situ* field surveys, which are more expensive and time consuming to perform. Remote sensing, however, cannot be considered a replacement for field surveys, both of which should be viewed as complementary efforts. Field surveys are required to interpret remotely sensed images and to evaluate the accuracy of such interpretation. Factors affecting the availability of remotely sensed data include cloud cover, sea state and water clarity. To date, most remote sensing efforts utilizing spectral imaging (e.g. hyperspectral data) have been directed toward research of potential applications, with little attention paid to operational realities (e.g. cost of existing capabilities to discriminate and map coral environments). Regardless of these constraints, remote sensing remains the only viable means of producing consistent and comprehensive coral reef ecosystem maps over the next 5 to 7 years.

Executive Order 13089 encourages the use of existing remote sensing technologies to map U.S. coral reef ecosystems, and supports continued research to refine its capabilities as an applied ecosystem management tool for coastal managers. The Working Group recommends a hierarchical approach to mapping these coral reef habitats, using a suite of remote sensing platforms ranging from satellites, to aircraft, to *in situ* field surveys.

Remote sensing technology can generally be grouped by the resolution (pixel size) of the resulting data. This resolution is affected by both the altitude of the platform from which data are collected and the design of the instrument or camera. First, *low-resolution satellite platforms*, such as NASA's SeaWiFS (Sea-Viewing Wide Field-of-View Sensor) and NOAA's AVHRR (Advanced Very High Resolution Radiometer) acquire synoptic data that range in pixel size from 1 to 10 km2. *Moderate-resolution satellite platforms* such as LandSat, SPOT, and human-occupied spacecraft (Space Shuttle, International Space Station) produce data with pixels ranging from 10 - 30 m2, depending on the specifics of the acquisition. Instruments mounted on *fixed-wing aircraft and helicopter platforms* range in resolution, depending on the altitude and specific technology used, from sub-meter to 5 m features. A final category of *classified remote sensing images* from the National Technical Means (NTM) Program would also have high resolution. NOAA has requested access to selected NTM data to produce benthic habitat maps and to augment civilian data acquisition of benthic habitat data.

Aircraft Platforms

Historically, high-resolution benthic habitat maps of large coastal areas have been produced from color aerial photography (NOAA/FMRI 1998). An important advantage to using aerial photographs is their widespread availability and ease of analysis. Color aerial photographs at scales of 1:12,000 to 1:24,000 have a resolving power of 0.5 to 1 m. However, conventional photo-interpretation techniques define polygons at 10 to 20 m in size due to prohibitive time constraints and the practical difficulty of mapping smaller features. Even with such "scaling up," standard photo-interpretation is very time consuming. Experts must manually classify habitats based on textures and colors in the image and their own knowledge of the distribution of benthic habitats. An alternative to this approach is to digitally scan the photo at a resolution consistent with its scale and then classify the resultant digital image using image-analysis software. While this approach is much faster than the conventional method, a disadvantage is that the digital image has poor spectral resolution (caused by overlapping, broad color bands, i.e., red, green, and blue), which limits the analyst's ability to discriminate between certain types of benthic habitats.

In an effort to expedite the analysis of aerial photographs, experiments are underway that combine the advantages of the above techniques. In this technique, aerial photographs are digitally scanned and a portion of the classification effort is computer automated as a "preclassification" step to standard photointerpretation. This technique shows promise for increasing the efficiency of deriving benthic habitat maps from photographs.

Multi- and hyperspectral remote sensing systems offer the tremendous advantage of increased spectral resolution. Multispectral systems have been successfully used to map coral reef ecosystems and to identify other benthic habitats, such as sand, algae and seagrass (Mumby et al. 1997). Recently, hyperspectral sensors have been used in relatively small geographic areas to map benthic habitats, including coral reef features (Mumby et al. 1998). Hyperspectral data contain far more information (i.e., characteristic spectral signatures) per image than a single conventional red-green-blue (RGB) color image (photograph), and significantly more information than multispectral data (Holasek et al. 1997). These studies show great promise for digital mapping of coral reef habitats. However, hyperspectral mapping generates large data sets and, to date, no regional benthic habitat maps have been generated from this technology. NOAA is currently conducting experiments in the U.S. Virgin Islands and Puerto Rico to explore the feasibility of synoptic habitat mapping using hyperspectral images.

Satellite Platforms

Satellite imagery has been used to map general benthic habitat types (e.g., sand, seagrass, coral, hard substrate) in coral reef environments. While lacking the spatial or spectral resolution of aircraft obtained data that enables detailed mapping, satellite imagery offers the advantages of increased frequency of coverage, extensive coverage at low cost, archival data and fast results. Satellite imagery also assures continuity across areas not covered by aircraft. At present, satellites can provide resolutions (pixel size) ranging from 1 km2 to less than 10 m2.

Moderate Resolution: Landsat Thematic Mapper (TM). This sensor has been used to map several types of bottom cover in coral reef environments (Mumby et al. 1997; Luczkovich et al., 1993). The TM can provide adequate resolution for planning aircraft missions, and also permits rapid response to reported bleaching events (e.g., at least several images per year in the Pacific, and biweekly coverage in the Caribbean). A TM sensor has been flying for 17 years. While data collection over coral reef regions has been rare, some key regions in the Pacific, such as Hawaii and Guam, have been covered at least once during this time, permitting some change analysis to be conducted. The launch of the Landsat 7 satellite potentially offers systematic, multispectral coverage of coral reefs at 30 m resolution, and panchromatic coverage at 15 m resolution. Unlike the earlier sensors, the TM on Landsat 7 is fully calibrated, allowing comparable processing for TM, aircraft and ocean-color sensors.

Moderate Resolution: Space Shuttle and International Space Station. Medium-format cameras have been used to photograph Earth from low orbits (median 176 nautical miles, 326 km) since the early 1970s. As with color aerial photography, color orbital photography can be interpreted from prints, or digitized in three bands (red, green, blue) and classified (Webb et al. 1999; Robinson et al. 1999). A nadir-looking photograph will have resolution ranging from 10 to 50 m2, depending on the specifics of the mission and camera. Although the photographs are more variable in look angle than other remote sensing platforms, most slightly oblique photographs are also suitable for use as remote sensing data (Robinson 1999). The digital images can be referenced to a map so that they can be combined with other mapping data. Because data is collected by human observers, it has been pre-screened for heavy cloud cover. Reef areas, especially in the Pacific, have been routinely photographed for the last 20 years. Continuous observations from the International Space Station (ISS, to be occupied beginning in the year 2000) will provide opportunities to collect imagery for those areas that have not yet been photographed under low-cloud conditions. ISS photographic capabilities include medium-format cameras, electronic still cameras, and high-definition television. ISS will also be equipped for mounting other instruments, including hyperspectral sensors, that may be useful for reef mapping at moderate resolutions.

Low-resolution: SeaWiFS and AVHRR. The ocean color sensors in SeaWiFS have the potential to provide a standard global coverage of reef areas at 1 km resolution. These sensors can identify shallow water areas, potentially distinguish live bottom from dead bottom, and provide consistent positional accuracy. These functional capabilities at this resolution have been demonstrated with 1-km data from the NOAA's AVHRR satellite, which has been used to produce the first accurate estimates of seagrass loss in Florida Bay and the Florida Keys during the past 10- years (Stumpf et al. 1999). One advantage to use of SeaWiFS is the ability to rapidly produce global color-based maps that can serve as a reference with which to plan the acquisition of higher resolution data, and to organize higher resolution data as it is acquired and processed.

Other Sensors: MOS (500 m) and SPOT (10-20 m) data can be incorporated as appropriate.

Hierarchical Mapping Strategy

Based on the requirements and needs identified by the Working Group, and the Task Force objective to comprehensively and consistently map U.S. coral habitats, a phased-in, multiplatform approach is recommended. All U.S. coral reefs should be mapped with low- resolution platforms (e.g., satellites). The Working Group recommends that the Long-Term Acquisition Plan of the Landsat 7 mission continue to obtain imagery over the world's coral reefs and make these data easily available for many users. Local, high-priority areas will require relatively high-resolution maps derived from sensors mounted on aerial platforms, including multi- and/or hyperspectral instruments and color photographs.

As stated in Section I, this document is an evolving one because its recommendations are likely to change based on changes in funding levels, program priorities and technology. Commercial firms are now taking many of the existing remote-sensing mapping tools out of the research and development mode and into the realm of applied habitat mapping. Several commercial and Department of Defense satellites proposed for 2000 and beyond, for example, may provide better spatial resolution at lower costs. Thus, an area such as the Federated States of Micronesia, for which the Working Group currently recommends the use of Landsat 7 images, may ultimately be mapped via higher-resolution tools.

This plan does not contain detailed descriptions of the logistical requirements for the acquisition of digital data, post-processing of those data, validation of draft maps, and development of final digital coral reef ecosystem maps, bathymetry maps or shoreline maps. The Mapping and Information Synthesis working group will continue to work closely with our federal, state and local partners to ensure coordination among these agencies in completing these mapping activities. Also, as interim products, such as aerial photography, bathymetry, or high resolution shoreline are completed, these will be made available to our working group partners.

IV. MAP INFORMATION SYNTHESIS: EXISTING DATABASES AND PRODUCTS

ReefBase. Currently, the only uniform reef maps available for all the U.S. reefs are part of the larger set of maps compiled by the World Conservation Monitoring Center and distributed as part of ReefBase (ReefBase 1998, produced by the International Center for Living Aquatic Resources Management). These maps were compiled from existing charts and information at a uniform 1 km pixel size. Although the maps are uniform in scale, they are presently constrained by data source limitations and data interpretation. ReefBase also accumulates ground-based data on aquatic resources that are integrated with the maps. Successful pilot projects have been completed for integration of NASA data with WCMC/ICLARM projects. SeaWiFS data can be used to improve the accuracy of the ReefBase maps. Georeferenced Space Shuttle photographs have been used as base maps for display of ReefBase attributes in a prototype GIS.

An initial step in developing this plan was to obtain information for all U.S. islands on the availability of digital benthic habitat data and associated baseline information, such as digital shorelines and bathymetry. The Working Group conducted two data inventories: (1) a mail questionnaire, and (2) a series of site visits to Florida, the U.S. Virgin Islands, Puerto Rico, Hawaii, Guam, Saipan and American Samoa. Table 1 provides an overview of the inventory results. See Appendix 2 for a summary of data and information availability for each island, state and territory. In addition to the information compiled on the availability of digital habitat data, many Island hardcopy and technical reports exist that will aid in interpreting new acquired habitat data and provided a historical perspective.

Table 1. Existing databases and products

	Digital Coral Reef Maps	Satellite Imagery	Recent Aerial Photography (<10 yrs.)	Aerial Hyperspectral Data	Digital High Resolution Shoreline	Digital Shallow Water Bathymetry
American Samoa	Unavailable/Unknown	Available	Available	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
CNMI	Incomplete	Available	Incomplete	Unavailable/Unknown	Incomplete	Unavailable/Unknown
Florida Keys	Incomplete	Available	Available	Incomplete	Available	Available
Fed. Sts. Micronesia	Unavailable/Unknown	Available	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Guam	Incomplete	Available	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Main 8 Hawaiian Is.	Incomplete	Available	Available	Incomplete	Incomplete	Incomplete
NW Hawaiian Is.	Unavailable/Unknown	Available	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Marshall Islands	Unavailable/Unknown	Incomplete	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Palau	Unavailable/Unknown	Incomplete	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Puerto Rico	Incomplete	Available	Incomplete	Incomplete	Available	Available
U.S.Virgin Islands	Incomplete	Available	Available	Incomplete	Available	Available
other†	Unavailable/Unknown	Incomplete	Available	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown

Available
Incomplete
Unavailable/Unknown

V. MAPPING IMPLEMENATION

Baseline Mapping Requirements

(1) Shallow Water Bathymetry

Bathymetry is a critical thematic data layer for many mapping activities. Bathymetry depicting water depths of less than 100 m is needed to identify and locate navigation hazards and shipping channels, predict and manage the damage from floods and storms, identify and monitor critical fish habitat, and document the location and extent of shallow coral reef ecosystems. Bathymetry also is required to fully utilize remotely sensed data to correct for light attenuation. Light received by the sensor is affected by the distance that it must travel through the water column. Fortunately, most corals are found in shallow-water environments of less than 30 m. Bathymetry of the Pacific Islands has not been extensively acquired. Recent efforts to gather high-resolution shallow water bathymetry have focused on southern Molokai, Oahu, Kauai, and Maui. Elsewhere, low-resolution bathymetry from mapped sources, such as NOAA nautical charts, has been used. It has, however, been more than 50 years since some of this information was updated. As a result, efforts should continue to acquire high-resolution bathymetry for shallow waters. Deeper reef bathymetry is also not generally available for the Pacific, Florida or much of the U.S. Caribbean, and efforts need to focus on these updating and improving these data sets.

Several technologies to measure bathymetry exist. Bathymetry for certain applications and depths to 25 m can be derived from remote-sensing techniques, although optimal conditions of water clarity are required. Airborne LIDAR, which utilizes an active, laser-based technology, can produce very accurate (+/- 30 cm), detailed bathymetric charts to 25-50 m depth in clear waters. In partially turbid waters, the LIDAR system can provide bathymetry to depths approximately 2.5 times the depth at which aerial photography can depict the ocean bottom. Costs of LIDAR range from $900 to $1,800 per sq km depending upon the horizontal spatial resolution needed. These costs include both data collection and the production of digital bathymetry maps.

(2) Deep Water Bathymetry

Deep water (> 50 m) bathymetry also is crutial for many mapping activities, including coral reef ecosystem mapping. Ship-based acoustic surveys using multibeam depth sounders have successfully produced bathymetric maps with vertical accuracies of +/- 15 cm from depths 10 m to 500 m and greater. Bathymetric data collected with multibeam systems is georeferenced, thus providing valuable information for identifying specific features or for follow-up mapping to detect change. In addition to providing highly accurate bathymetric maps, the system provides backscatter, which can be used to map the roughness of the seafloor.

(3) Digital Shoreline Maps

Shoreline is a critical thematic layer because of its importance in linking land-based and water-based coastal zone management issues. An accurate, high-resolution shoreline is the base map upon which all other thematic data layers are superimposed. In addition, datum adjustments must be applied to the shoreline to properly place this key feature on the earth in a GIS. For the Caribbean islands, high-resolution (nominally, 1:20,000 scale) shoreline data are available. In the Pacific, accurate, high-resolution digital shoreline data are generally unavailable. NOAA nautical charts and USGS quadrangle maps are the most widely available sources of information. These maps have not been updated for many years, and generally are unavailable as digital data. Moreover, they are drawn in old datums and, in some cases, are known to depict islands as much as 1 to 2 nautical miles from their actual location on the Earth. Efforts must continue to develop accurate, high-resolution, datum-corrected digital land (shoreline) maps for the Pacific.

(4) Habitat Classification

A required step in developing digital map products is the formulation of a benthic habitat classification scheme. Work is under way in the Caribbean with Working Group members and other experts to develop a comprehensive classification system specific to that region. The approach involves developing a hierarchical biological and physical classification scheme based on the needs of the management community, the strengths and weaknesses of existing classification schemes for the area and, most importantly, the limitations of each technology (e.g., aerial photographs, hyperspectral). The digital data derived from each method can be used to generate maps depicting a certain level of classification. For example, aerial photographs can be used to produce maps that depict coral reef types, but are unsuitable for mapping individual species of coral. The more detailed the classification scheme, the more highly resolved the data must be to support the classification.

The development of a marine habitat classification scheme is under way in the Pacific as well. Holthus and Maragos (1995) have produced a detailed classification system that covers many island geomorphologies and substrate types that occur throughout the Pacific. More recently, the Pacific Marine Environmental GIS Work Group, a consortium of federal, state and academic partners, is leading the development of an updated classification system for the Pacific Islands. The applicability of these classification schemes to the features identifiable in the remotely-sensed imagery will need to be evaluated.

In summary, accurate, high-resolution bathymetry and shorelines are important data sets that aid in the development of coral reef ecosystem maps. In addition, a hierarchical classification system must be developed to map benthic habitats.

Overview of Island/State Mapping Requirements and Priorities

Representatives of the Working Group met with state and island partners in a series of meetings and site visits to determine mapping requirements in these areas. Based on the consensus of the territory and state Working Group partners, priorities were determined for geographic areas to be mapped, preferred map resolution, and proposed products. These priorities are summarized in Tables 2 and 3, and include information on where, when, and how to map coral and other benthic habitats. Most importantly, cost estimates are provided for various remote-sensing technologies. The cost estimates have been broken down by high- and low-resolution mapping platforms.

It is important to note that in developing the following information on coral mapping requirements and needs, the Working Group treated the Mapping Implementation Plan as a high priority for each island. When other activities are integrated into the U.S. CRTF Action Plan, however, the mapping of coral reefs may range from high to low priority relative to other important action items identified by island and state partners. The overall priority placed on mapping is presented in the All U.S. Islands Plan. This comprehensive coral reef management, research, monitoring and assessment document will strongly influence the U.S. CRTF Action Plan.

The Islands agree that coral mapping is a high priority, however, it is felt that funding for this important task should be accomplished through internal reprioritization of Federal agencies existing budgets as directed in the Presidential Executive Order. However, reprioritization of funds will only enable digital high-resolution maps to be completed for a portion of U.S. coral reef ecosystems within five years. If new funds are provided by Congress, the priority for allocation remains with the Islands, as adopted as a resolution by the U.S. CRTF.

Atlantic Ocean/Gulf of Mexico

(1) Caribbean

In the U.S. Virgin Islands (USVI) and Puerto Rico, high-resolution benthic habitat maps are under development for the U.S. Virgin Islands and Puerto Rico. In 1999, NOAA's National Ocean Service (NOS) and National Marine Fisheries Service (NMFS) initiated a coral mapping study with a series of partners, including the USVI National Park Group (NPG) , the USVI Department of Planning and Natural Resources, and the Puerto Rico Department of Natural and Environmental Resources, and the USGS. The objective of the study is to consistently and comprehensively map the distribution of shallow-water coral reefs and other benthic habitats in and around these islands. Made possible through the strong commitment of many governmental, academic and private-sector partners, the study serves as a model for integrating a large number of partners to develop high-resolution digital maps of benthic habitats.

Data acquisition was completed in April 1999. NOAA aircraft were used to conduct color aerial photography and hyperspectral imaging. Color photographs were taken of all U.S. Virgin Island and the majority of Puerto Rico shorelines, and offshore to water depths of approximately 20 m. The aerial photography mission was flown primarily at an altitude of 24,000 feet (1:48,000 scale). An important complementary component of this investigation was a suite of airborne and waterborne hyperspectral experiments conducted at St. Croix and Buck Island, U.S. Virgin Islands, to determine the feasibility of mapping regional benthic habitats using hyperspectral remote sensing technologies. The pilot study is tentatively scheduled for completion by the end of 1999. Follow-up work includes: (1) completing the acquisition of aerial photography of Puerto Rico; (2) determining how best to process the aerial images; (3) developing a benthic habitat classification system that is appropriate for the area; (4) draft digital maps of benthic habitats; and (5) development and distribution of final products.

These maps will prove useful to a wide array of research and management activities. In both Puerto Rico and the USVI, coastal development and land use have been identified as primary stressors on coral reef ecosystems. Managers lack critical information that can help or assist them in regulating and evaluating status and trends of reef ecosystems and the effects of management decisions. Coral reef maps will serve as a basis to integrate monitoring, permit evaluation, land use activities and benthic habitat characterization. In addition to the need for coral reef maps, other thematic maps, such as bathymetry and land-use activity maps would greatly improve the ability of these islands to effectively manage and protect these resources.

As a result, the working group will work to identify and fill-in gaps that exist in the aerial photography and hyperspectral data. The working group will work to identify sources of land-use data and make these available too. The cooperative partnership that has been established with Puerto Rico and USVI has been instrumental in accomplishing the working group's goals. We will continue to work closely together, making interim products available as soon as possible and in developing technologies and training activities that can be used immediately to address coral reef management issues.

(2) Gulf of Mexico

In Florida, NOAA and the Florida Marine Research Institute used aerial photogrammetry techniques from visual overflight data to map approximately 60% of the benthic habitats of the Florida Keys coral reef ecosystem (NOAA/FMRI 1998). Digital benthic habitat maps were produced and published as a CD-ROM. That CD-ROM has been made widely available to the scientific and management communities. The identified benthic habitats were classified into 23 major "types" (e.g., sparse seagrass, patch reef, fringing reef). While this work could serve as a "model" for other Coral Reef Initiative efforts conducted in other regional ecosystems, it should be pointed out that the mapped areas would be subject to errors in classification and "non-identification." These problems stem from the methods of collecting and assimilating data from aerial photography, sub-optimal water transparency during overflights, cloud cover, and the bulk of functional habitats below one optical depth.

An even more serious problem is that, despite its economic and ecological importance to the nation, about 40% of the Florida Keys remains unmapped. The majority of Florida Bay, most of the area from Key West past the Dry Tortugas, and "unmapped areas" depicted on the CD-ROM maps remain to be characterized. Some of the Keys' most productive coral reefs fall in these areas. Places like the Marquesas and the Dry Tortugas, where NOAA's National Marine Sanctuary Program and the U.S. National Park Service are currently in the process of establishing innovative spatial protection zones to conserve marine biodiversity and build sustainable fisheries. As a result, these areas and, in particular, the Dry Tortugas region, are high-priority areas for additional mapping. In fact, both the Florida Governor's Office and NOAA's advisory council to the Florida Keys National Marine Sanctuary and the National Park Service have identified the Dry Tortugas as a "High Priority" area for mapping.

Pacific Ocean

While approximately 85% of U.S. coral ecosystems are found in the Pacific Ocean (Clark and Gulko 1999), only a small fraction of these reefs have been digitally mapped at a resolution sufficient for management, research and monitoring activities. Fortunately, the Working Group was able to develop a comprehensive strategy to map these coral reefs by drawing on the experience of researchers and managers and the results of applied mapping studies conducted in Florida, the Caribbean and Hawaii.

The first step in developing the Working Group's mapping strategy (MISWG 1999a) for the Pacific Islands was to conduct a comprehensive inventory of existing digital coral reef maps. The Working Group conducted an intensive reconnaissance effort throughout several major Pacific islands. The work was conducted through four site visits (to Hawaii, Guam, the Commonwealth of the Northern Mariana Islands, and American Samoa), a mailed questionnaire, and via phone and electronic mail. This effort identified much data to support coral reef mapping (e.g., existing aerial photography) as well as priority areas for mapping at relatively high resolution. Priorities were defined based on ecological, political and economic concerns (Table 2). Each of the major island areas, and a summary of the Working Group's findings, are briefly described below. Tables 2 and 3 summarize the islands' and state partners' needs, and the costs associated with developing digital benthic habitat maps at both high and low resolutions. The working group recognizes that producing coral reef ecosystem maps for accessible areas will be significantly easier than for remote areas. The cost of in-situ groundtruthing, acquiring georeferenced mapping data, and other logistical-support activities will be far greater in these areas.

Table 2. Mapping priorities and estimated costs ($K) for high-resolution digital mapping of benthic habitats

Priority	Location	Reef Area (km ^{2})	Data Collection	Draft Maps	Final Product	Total Cost
†	Puerto Rico/USVI	5201			200	200
1	Main 8 Hawaiian Islands	2535	350	650	350	1350
2a	Guam	179	50	50	50	150
2b	CNMI	579	100	150	100	350
3	Amer. Samoa	296	50	100	50	200
4	NW Hawaiian Islands	11331	1450	2850	1450	5750
5	Midway	223	50	100	50	200
6	Florida Keys	988	150	250	150	550
7	other*	706	100	200	100	400
					total:	**9150**

† Approximately $200K needed to complete project.

Estimates of Pacific coral reef ecosystem area in Table 2 are from Hunter (1995). Caribbean coral reef ecosystem area estimates are from Miller and Crosby (1998), except for the Florida Keys, where the reef ecosystem area was estimated as that portion not mapped in the Benthic Habitats of the Florida Keys project (NOAA/FMRI 1998). The order of mapping priorities is based on: (1) population/ecosystem stress level, (2) lack of existing maps, (3) coral area, (4) priorities identified in the All Islands Plan, and (5) cost of mapping relative to other areas. Values (expressed in $1000s) were determined by multiplying the area to be mapped by the estimated cost of mapping per unit area (data collection=$125 per sq km; draft maps=$250 per sq km; final product=$125 per sq km) and then rounding up to the nearest $50,000 to simplify presentation.

* Johnston, Palmyra, and Wake Atolls, Baker, Jarvis, and Howland Islands, Kingman Reef, and Freely Associated States.Cost estimates for these islands do not include the transport of equipment and aircraft between remote locations.

(3) Hawaii

For the state of Hawaii, the highest-priority is benthic habitat mapping of the eight main Hawaiian Islands and the surrounding small islands and reefs. The northwest Hawaiian Islands have been identified as a priority by NOAA's National Marine Fisheries Service and the U.S. Fish and Wildlife Service. It was agreed, however, that data acquisition must first be conducted for the eight main islands. The geographic area priorities are: the southern coasts of the main Hawaiian Islands (except Lanai and Niihau), all of Oahu, and eastern coast of Maui. The Working Group's recommendation is to conduct experimental high-resolution mapping in the northwest Hawaiian Islands, including Midway, in combination with satellite-based remote sensing, during the first few years of study. Midway Atoll, at the extreme northwest end of the Northwestern Hawaiian island chain, is under U.S. jurisdiction, but is not a part of the State of Hawaii. As it is generated, digital data will be rapidly transferred to the Hawaiian partners, These data include georeferenced TIFF images of both aerial photos and hyperspectral imagery. In addition, where appropriate, raw imagery of full hyperspectral bands for selected areas should be made available to meet multiple assessment needs.

In Hawaii, some citizens and institutions raised the concern that providing high-resolution maps to the public could increase the potential for exploitation of coral resources. The Working Group offered several ideas for minimizing this concern, including investigating the possibility of degrading the geopositional accuracy of selected map features. Also, as draft coral reef ecosystem maps are reviewed and verified, generalization of certain features may be considered in response to concerns about the depiction of cultural sites.

(4) Territories, Commonwealth and Freely Associated States

The islands of Guam, American Samoa and the Commonwealth of the Northern Mariana Islands (CNMI) were determined, by consensus, to be high-priority areas for mapping at the highest level or resolution practicable. These small but important islands could use maps immediately to protect, conserve and manage their coral reef ecosystems. While only some of these islands may need the high-resolution maps derived from data collected by aircraft, all the islands should be comprehensively mapped using data from satellites, such as Landsat 7. In addition, every attempt should be made to acquire high resolution imagery of Howland Island and Baker Island. Both are small islands near the air transit corridor between Hawaii and American Samoa. These islands possess areas of high biodiversity. However, due to their remoteness, any mission to acquire imagery of these islands will require special logistical support.

(5) Guam

Many institutions, including the Guam Coastal Management Program, Division of Aquatic Wildlife Resources, Guam Environmental Protection Agency, and the University of Guam, require high-resolution maps of coral reefs to support their coastal zone management and research activities. These activities include boundary delineation of protected areas and the identification of areas having high sediment runoff relative to the location and distribution of coral reefs. The Working Group recommends the use of aircraft platforms to map these benthic habitats at high resolution.

(6) American Samoa

High resolution images are needed to address the issues and challenges faced by American Samoa. Some needs of local agencies include: spatial characterization of reefs and associated benthic habitats, better understanding of the relationship between land and sea, watershed delineation, and mapping products suitable as educational and interpretive tools. Conducting a data acquisition mission to American Samoa requires special logistical planning. Opportunities may exist to partner with organizations located locally to acquire data. The working group will pursue these opportunities. American Samoa ranks coral reef mapping as a high priority. However, they have indicated to the working group that its final ranking of geographic area priorities will need to await the results of decisions on what Coral Reef Initiative proposals receive funding.

(7) Commonwealth of the Northern Mariana Islands (CNMI)

In the CNMI, the islands of Saipan, Rota and Tinian were identified by the island's Coastal Zone Management Program as the highest-priority islands for high-resolution coral reef mapping. The Working Group's recommendation is to initially map the remaining 11 islands in the archipelago using satellite platforms. If adequate funding becomes available, however, all coral reefs within the CNMI should be mapped using high-resolution technology.

(8) Freely Associated Islands

The Freely Associated Islands have close ties to the United States, which governed these islands for over 40 years as Territories following World War II. The "Freely Associated" Islands (FAI) of Micronesia (i.e., the Republic of the Marshall Islands, the Federated States of Micronesia and the Republic of Palau) possess coral reefs with the highest biodiversity of any US or FAI reef ecosystems. The belief is that the total area of reefs in the FAI is much higher than that of the US Flag Islands. Many of these reefs are believed to be in good to excellent condition. As such, they provide an important "baseline" for studying the effect of both anthropogenic and natural disturbances. They also serve as a source of natural products of potential biomedical value. Reefs within the jurisdiction of the island nations may be among the best choices for marine protected areas of global importance. There are less political and social constraints at establishing MPAs in uninhabited areas, and many are situated near corresponding candidate MPAs in the US Pacific Islands. A mapping mission at Wake Atoll, for example, could be extended to cover several atolls in the Marshall Islands. A mapping mission to Guam could be extended to cover islands and atolls in Palau and the FSM. In concert with other CRTF initiatives to promote establishment of MPAs in the FAI, coral reef mapping in the latter can greatly stimulate, publicize or otherwise assist in these ventures. The renegotiation of the Compacts of Free Association in the next few years could also include economic incentives for the individual FAI committees to establish MPAs and their long-range management. Mapping of these candidate areas would be a crucial first step in this process.

For the Federated States of Micronesia (approximately 607 islands), the Republic of Palau (more than 200 islands) and the Republic of the Marshall Islands (five islands and 29 atolls), the Working Group's recommendation is to use satellite technology for initial coral reef mapping efforts. Due to the vast expanse of these areas, preliminary mapping at relatively low resolution (0.3 to 1 km2) will allow researchers to identify those areas that require high resolution mapping. In addition, the working group is in discussions with the civilian and classified satellite remote sensing community to determine the best way forward to map these important areas.

(9) Other U.S. Flag Islands

Eight other small islands and atolls in the Pacific are under the jurisdiction of the U.S. government: Midway, Wake, Johnston, and Palmyra Atolls, Kingman Reef, and Jarvis, Howland, and Baker Islands. Of these, all but Wake Atoll, Palmyra Atoll, and Kingman Reef are National Wildlife Refuges and are under administration of the U.S. Fish and Wildlife Service. All eight possess exceptionally important biodiversity values and coral reefs. The working group recommends collection of high resolution imagery of Midway Atoll as part of the northwest Hawaiian Islands mission. The aircraft can also collect imagery along selected corridors in this vast coral reef ecosystem during transit between Midway and the main Islands.

Product Development

A suite of coral reef mapping products was defined by the various potential users of digital benthic habitat maps. Some groups, such as nongovernmental organizations, need worldwide and regionwide coral distribution maps to validate and update existing broad-scale coral distribution databases, for example, the ReefBase database housed at the ICLARM (ReefBase 1998). Digital imagery produced from satellites, such as SeaWifs and Landsat, may provide sufficient data content and resolution for these types of users (Figure 1 provides an example of low- to moderate-resolution imagery). In addition, this type of digital product is sufficient as an interim product for particular areas (e.g., the northwest Hawaiian Islands). In areas in which relatively high populations occur or are increasing, high-resolution digital imagery and hard-copy map products, such as those produced for the Florida Keys (Figures 2 and 3 provide examples of high-resolution imagery and the resultant map product) are required for local management decisions. Many island-based Coastal Zone Management Programs need to conduct spatial analyses to determine sensitive areas requiring increased protection and regulation. As a result, digital coral reef maps must be of sufficient spatial resolution (e.g., 5 m or less) to define the management boundaries of protected areas. Thus, the MIP cost estimates account for both high- and low-resolution products.

Mapping Cost Scenarios and Timing

Mapping coral reef ecosystems is an expensive activity, especially at high resolution. Acquiring imagery and other information requires airplanes, fuel, pilots and crew, landing and takeoff facilities, cameras, film, remote sensing instruments, and good weather. Extensive effort must be expended to establish the ground control locations needed for georeferencing the digital data. Once the information is acquired, it must be processed into draft maps, checked for accuracy and ground control, reviewed, edited, and finalized. The final coral reef ecosystem maps then need to be made available to the user community as digital data products over the internet and/or other media (e.g., CD-ROMs).

Based on the published literature (Green et al. 1999; Low et al. 1999; NOAA/FMRI 1998) and federal and state agency and private sector experiences in mapping coral and other benthic habitats, cost estimates were derived for data collection, draft digital map development (e.g., classification, field validation), and final digital map product costs. An estimated $500/sq km is required to produce high resolution digital coral reef maps. This value was used to estimate high resolution mapping costs based on Hunter et al. (1995) estimates of coral reef area by island (Table 2). For the six major Island and State areas that require high resolution coral reef maps, cost was estimated to be approximately $9,150,000. For all US coral reefs found in State, Territories, and Freely Associated States, low resolution (30 sq. m pixels) digital coral reef maps were estimated to cost approximately $450,000 (Table 3). Thus, the estimated total costs for digital mapping of US coral reef ecosystems is approximately $9.2 million dollars.

It must be noted that very little information exists to accurately derive the costs of mapping all U.S. coral reefs. Moreover, the costs of mapping remote areas, such as the northwest Hawaiian islands or the Republic of Palau, will be higher than areas like Puerto Rico or the eight main Hawaiian islands. Based on potential cost estimate errors (plus or minus 25%), changes in cost due to gains in technology and economic inflation, it is estimated that, over the next five–seven years, the cost of developing high resolution coral reef maps could range from $6 to $15 million dollars. If funding is obtained to initiate data collection and map product development, a detailed technical specification document will be developed. That document will have detailed cost estimates for data acquisition, data processing, data validation and logistical support, map verification, and final map product development and distribution.

Table 4 shows three funding scenarios assuming zero funding, $500K, and $1 million dollars per year allocated to digital mapping of benthic habitats for all U.S. coral reef ecosystems. Under a “no new money” scenario, only draft products can be developed for the U.S. Virgin Islands and Puerto Rico. NOAA plans to reprioritize internal funding so that data collection can take place for at least a portion of the main eight Hawaiian Islands during fiscal 2000. No monies are currently available for data processing or map development. Scenario 2 ($500k/yr) will enable digital high resolution map products to be developed for the USVI, Puerto Rico, eight main Hawaiian Islands, Guam, CNMI, and American Samoa by 2005. At this level of funding, high resolution products cannot be developed for the northwest Hawaiian Islands by 2007. At the $1 million per year funding level for seven years, most of the high-priority island areas could receive high-resolution digital coral reef maps. However, even under this funding scenario, the gaps in Florida Keys benthic habitat maps could not be completed. Approximately $1.3 to $1.8 million/year would be required to complete digital maps for all U.S. coral reefs within the proposed 5 to 7 year time-frame.

The order of geographic mapping priorities was based on the consensus reached among island and state partners and MISWG members using several criteria. These criteria included ecosystem stress (population), lack of digital maps, extent of coral coverage, mapping priority in the All US Islands Coral Reef Plan, and cost of mapping relative to other coral reef-related activities. The most difficult region to map will be the northwest Hawaiian Islands due to the great extent of coral area and inherent logistical problems. Therefore, the northwest Hawaiian Islands was ranked fourth for high resolution data collection, because of the relatively high costs ($5.8 million) to map this area. High resolution satellites of the near future may significantly decrease the costs of digital coral mapping in expansive areas, such as the northwest Hawaiian Islands.

Figure 1. Example of low- to moderate-resolution (satellite) imagery of Long Key area, Florida Keys

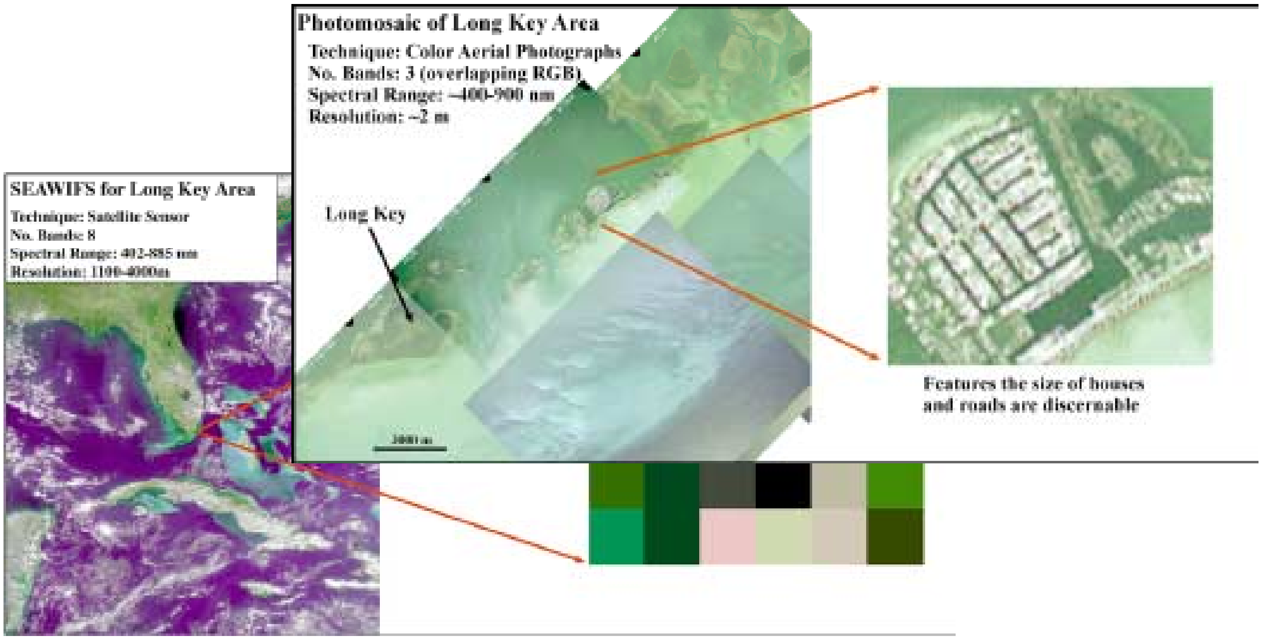


Figure 2. Example of high-resolution (aerial) imagery of Long Key area, Florida Keys

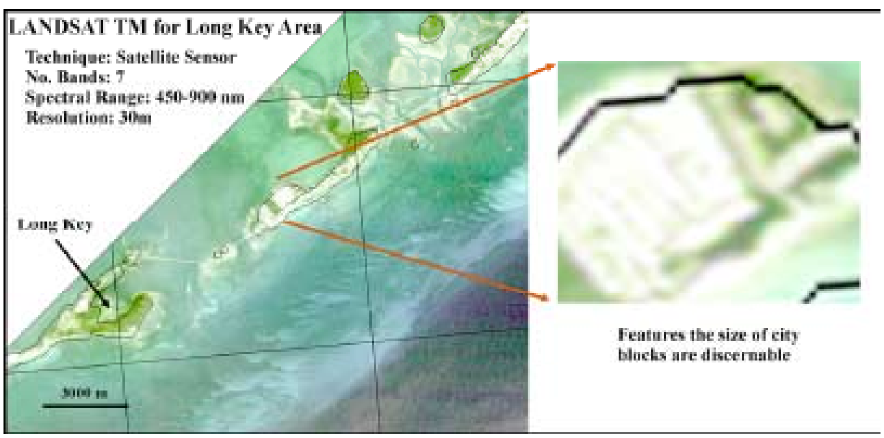


Figure 3. Example of GIS product using aerial photography that was classified into seven benthic habitat types

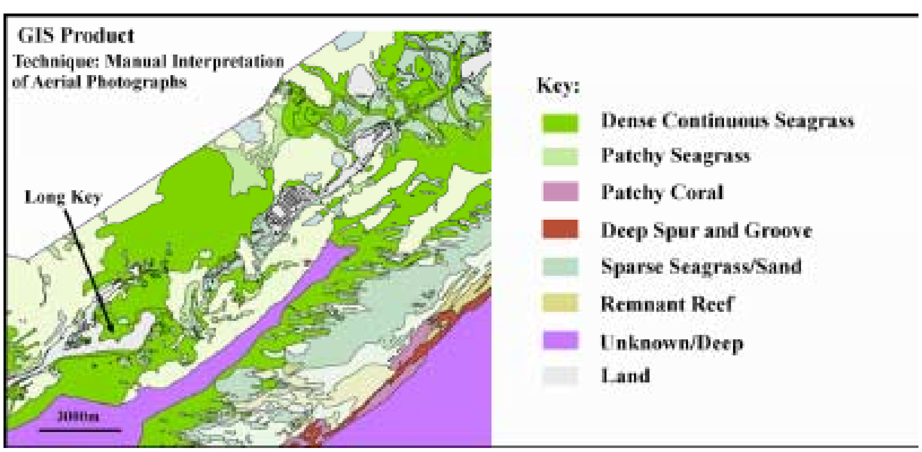


Table 3a-b. Estimated costs ($K) for Landsat TM(a) and SeaWiFS(b) low and moderate resolution digital coral reef mapping

3a. Landsat TM (Thematic Mapper)

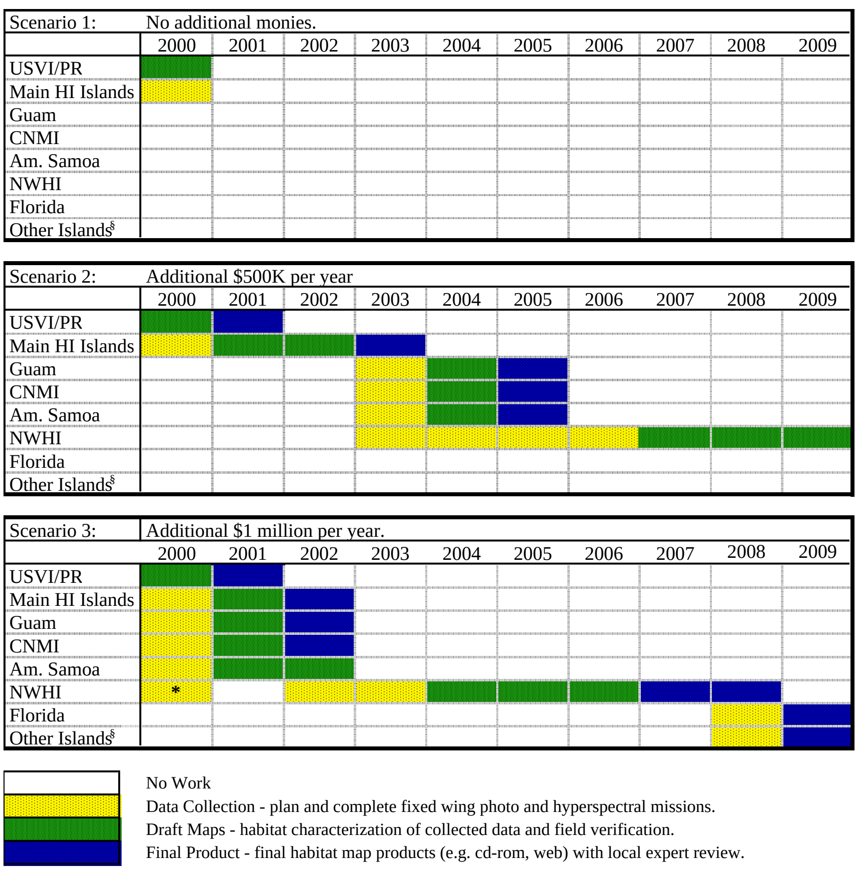
Location	Scenes	Historical Imagery ($3K/scene)	Labor ($2.8K/scene)	Hardware	Other ($0.7K/scene)	Total ($7.5K/scene)	Landsat 7 Imagery ($650/scene)
PR/USVI	3	$9.0K	$8.4K	$60.0K	$2.1K	$22.5K	$2.0K
Main HI Islands	10	$30.0K	$28.0K		$7.0K	$75.0K	$6.5K
Guam/CNMI	8	$24.0K	$22.4K		$5.6K	$60.0K	$5.2K
NW HI Islands	15	$45.0K	$42.0K		$10.5K	$112.5K	$9.8K
Midway	1	$3.0K	$2.8K		$0.7K	$7.5K	$0.7K
Am. Samoa	3	$9.0K	$8.4K		$2.1K	$22.5K	$2.0K
Florida	4	$12.0K	$11.2K		$2.8K	$30.0K	$2.6K
Miscellaneous §	17	$51.0K	$47.6K		$11.9K	$127.5K	$11.1K
						Total Cost	**Total Cost**
Total	61	$183K	$171K	$60K	$43K	**$458K**	**$40K**

§ Jarvis, Johnson, Palmyra and Wake Atolls and Baker, Howland and Kingman reefs, and Freely Associated States.

3b. SeaWiFs (Sea-Viewing Wide Field of View Sensor)

Annual Expense under NASA Management	
Labor	$15K
Travel/Supplies	$3K
Publication	$7K
Total Cost	$25K

a. Table 4. High resolution coral reef mapping under three funding scenarios



* Pilot study - approximately 20% of total data collection.

§ Jarvis, Johnson, Palmyra and Wake Atolls and Baker, Howland and Kingman reefs, and Freely Associated States.

Capacity Building in Islands and States

Based on discussions held with territory and island partners during the Working Group's reconnaissance trips, map products should be incorporated into the data acquisition and distribution plans to ensure that useful management products can be derived from the raw data. If federal resources are provided to island and state communities, a process needs to be established to ensure these partners receive the most useful mapping products. Most importantly, the U.S. Coral Reef Task Force and its Mapping and Information Synthesis Working Group must take an active role in ensuring the user community actively participates in the development, generation, distribution, and use of the coral reef ecosystem maps. This "capacity-building" will bridge the gap between one-time synoptic mapping efforts and coral reef ecosystem management. It also will elevate mapping efforts from "snapshot" investigations to the continual spatial monitoring of coral reef habitats. For example, an initial activity is under way in the U.S. Virgin Islands and Puerto Rico to develop a Classification Manual that describes methods and protocols for habitat classification and the development of map products. These types of products will aid in capacity-building throughout all of the islands associated with the United States.

VI. NEXT STEPS

This draft of the MIP will be submitted to the U.S. Coral Reef Task Force at the November task force meeting. Comments received from the task force and the public will be integrated into the next version of the MIP. This document will continue to evolve based upon mapping priorities and availability of funds. Please submit comments and questions to:

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IX. APPENDICES

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Appendix 2. List of available data and information to support coral reef mapping by island, state, commonwealth and territory

Information Source	Date* Developed	Information Description
American Samoa		
USGS	1990	Digital Orthophoto Quads
NOAA/HAZMAT	1999	Environmental Sensitivity Index maps being updated
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for five islands
NPS	n/a	digital data set of beach and nearshore reef communities for a 2 mile portion of Ofu Island
FWS	n/a	National Wetlands Inventory maps indicating presence/absence of coral
NOAA/NGDC	n/a	deep water NOAA/NOS bathymetric sounding data
Commonwealth of the Northern Mariana Islands		
USGS	1990	Digital Orthophoto Quads
U.S. Navy	ongoing	will conduct bathymetric surveys and B&W aerial photo mission to Tinian and Farallon de Mendilla
CRM	1999	numerous terrestrial and aquatic thematic data layers (e.g., coral presence/absence) digitized from USGS topographic sheets for Saipan
NOAA/HAZMAT	1999	Environmental Sensitivity Index map for Saipan available
CRM	1999	1:10K color aerial photography acquired
CRM	1996	1:10K color aerial photography available
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for eight islands
FWS	n/a	National Wetlands Inventory maps for Saipan
Federated States of Micronesia		
Univ. of Guam	1998	shoreline and coral reef extent for Kosrae, Chuuk, Pohnpei, and Yap digitized from 1:24K USGS topographic sheets
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for Kosrae, Chuuk, Pohnpei, and Yap (plus some other islands)
Guam		
USGS	1990	Digital Orthophoto Quads
NOAA/HAZMAT	1999	Environmental Sensitivity Index map for Saipan available
Univ. of Guam	1998	shoreline and coral reef extent thematic data layers digitized from1:24K USGS topographic sheets
GovGuam	1995	1:20K color aerial photographs of most of Guam available.
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography
NPS	ongoing	To be scanned, georeferenced and mosaiced during FY2000 for base map to preliminary reef inventory assessment by University of Guam/NPS. Natural color stereo aerial photography with associated ground control information: Agat Beach/Reef - 3 flight lines,
FWS	n/a	National Wetlands Inventory maps available
Hawaiian Islands (Main Eight)		
NRCS	ongoing	acquisition of 1:6K digital imagery to delineate 11 and 14-digit hydrologic units and to use in watershed assessment projects.
USGS	1990	Digital Orthophoto Quads
WPFMC	1999	generalized (various scales) GIS maps of islands and political boundaries (e.g., EEZ) used for FMP.
Univ. of Hawaii	1999	800+ in-situ spectra of coral reef ecosystem localities
DLNR	1994	SPOT images of eight main islands.
NOAA/NOS	1994	1:35K scale color aerial photographs of eight main islands
NOAA/HAZMAT	1985	Environmental Sensitivity Index maps available
DLNR	n/a	numerous digital data files available, including shoreline, some reef extent polygons, and some general bathy
NOAA	n/a	5 arcsecond bathy for entire Pacific region
Oahu		
Univ. of Hawaii	1998	Digital Airborne MSS data and georeferenced map (1:10,000) of reef and nearshore on Windward Oahu, Kailua - water depths 0 to 40m(original pixel resolution - 1m). Data are being trained/modeled with bathymetric data, and substrate classification currently

Information Source	Date* Developed	Information Description
Maui		
Univ. of Hawaii	1998	digital bathymetry and coral cover in and around Maalaea harbor.
COE	1998	low altitude bathymetric LIDAR for all of island
Molokai		
USGS	1999	1:10,000 scale color aerial photos of south shore of island
COE	1999	low altitude bathymetric LIDAR for south shore of island
Ogden Environ.	1994	reef coverages for portions of southeast Molokai
Kauai		
COE	1999	low altitude bathymetric LIDAR for south shore of island
Ogden Environ.	1994	reef coverages for portions of north Kauai
Hawaii		
Ogden Environ.	1994	reef coverages for Puako area in North Kohala district of the island
Lanai		
Ogden Environ.	1994	reef coverages for eastern portion of island
Northwest Hawaiian Islands		
FWS	n/a	digital maps of numerous themes, including NWHI wildlife refuges
Puerto Rico		
NOAA/NOS	ongoing	project underway to digitally map coral reef ecosystems from 1:20K and 1:48K color aerial photography and hyperspectral instruments
NOAA/NOS	1999	aerial photography at 1:24K and 1:48K scales
USGS/BRD	1999	benthic habitat maps of Vieques island and and Roosevelt Roads NAS at 1:9,600 scale
NOAA/NGDC	n/a	NOAA/NOS bathymetric sounding data at 3 arc second intervals
USGS	n/a	digital and hard copy maps of sediments, reefs, and detailed bathymetry for segments of the coastline
FWS	n/a	National Wetlands Inventory maps indicating presence/absence of coral
Republic of Palau		
Univ. of Guam	1998	shoreline and coral reef extent for Babeldaob digitized from 1:24K USGS topographic sheets
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for Babeldaob, Oreor, Belilou, and Ngeaur
U.S. Virgin Islands		
NOAA/NOS	ongoing	project underway to digitally map coral reef ecosystems from 1:20K and 1:48K color aerial photography and hyperspectral instruments
NOAA/NOS	1999	color aerial photography at 1:24K and 1:48K scales
NOAA/HAZMAT	1999	Environmental Sensitivity Index maps recently reviewed and updated
CDC/TNC	1999	Rapid Ecological Assessment maps for St.John and St.Thomas
CDC/TNC	1998	Rapid Ecological Assessment Maps for St.Croix
NPS of USVI	1986	marine habitat maps for St.John at 1:5,300 scale
NOAA/NGDC	n/a	NOAA/NOS bathymetric sounding data at 3 arc second intervals

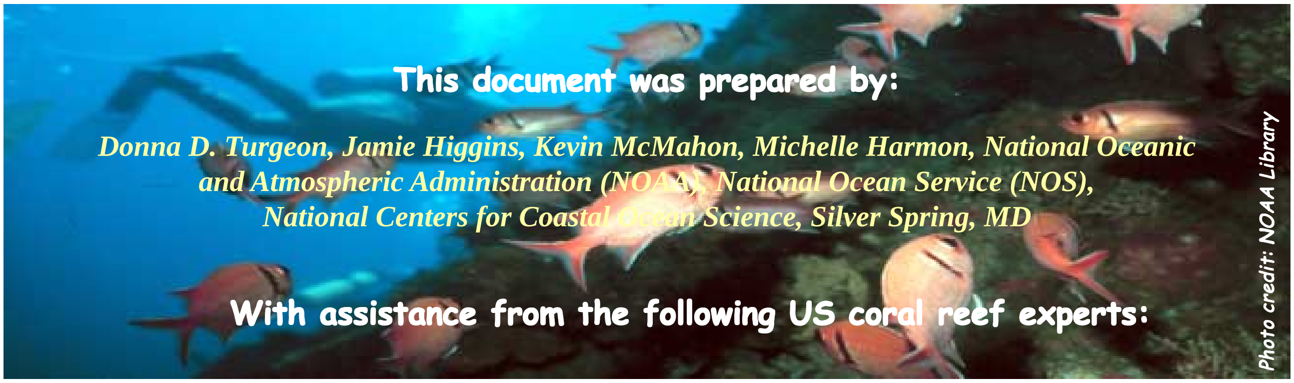
* Date of product development does not necessarily mean date of data collection.

A National Program to Assess, Inventory, and Monitor US Coral Reefs

Responding to what has been described as an internal clock, many coral species release clouds of sperm and expel millions of eggs at roughly the same time a predictable number of evenings after a summer full moon (e.g., August in the Caribbean and June in Guam). Warm ocean currents then transport the fertilized eggs away from the parent colony. Weeks and perhaps even months later, the developing embryos settle out from the plankton to continue the reef-building process. Through the assessment, monitoring, and proper management of coral reefs, we can ensure the future of this priceless natural resource.

Prepared for

The US Coral Reef Task Force



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A National Program to Assess, Inventory and Monitor US Coral Reef Ecosystems

Introduction

This document describes the actions to be undertaken by the US Coral Reef Task Force to implement a nationally coordinated, long-term program to assess, inventory, and monitor[1] US coral reef ecosystems (Program). At present, a number of programs are being operated by various governmental and private entities at local and regional levels, but these generally lack a consistent design, purpose, and intercomparable data sets, and leave wide gaps in coverage. This program seeks to integrate existing Federal, State, Commonwealth, Territorial, and non-governmental efforts into a national monitoring network. Where needed, the program will help fill critical gaps in our knowledge of reef ecosystems by either encouraging the expansion of existing monitoring programs or by sponsoring activities that will lead to the establishment of new long-term monitoring sites. These activities will be accomplished through partnerships with resource managers, scientists, and volunteers who will work together to build local capacity to assess and monitor coral reefs.

Thousands of snorklers and divers explore and photograph our nation's coral reef resources.

- ***Mission:*** Managers, scientists, and volunteers will cooperate to establish an integrated network of local and regional monitoring programs that will provide the information and data needed to develop coherent management strategies for sustainable US coral reef resources.
- ***Goal:*** Create a nationally coordinated, long-term program within two years to inventory species, assess conditions, monitor trends, and predict changes in US coral reef ecosystems.

[1] *Assessing, inventorying, and monitoring are essential data-gathering strategies for coral reef management. Conducting a literature search, inventorying species, and assessing baseline conditions are the initial steps in creating a "snapshot" appraisal of the status and threats to reefs and the various management options to protect them. Such an assessment provides the basis for choosing the goals, sites, and scope of a monitoring program. In turn, long-term monitoring of coral reefs at established locations provides documentation of reef change over time, the reasons for the changes, and much of the justification for management interventions such as restoration, surveillance, and controls over the harvest of reef resources.*

This scientist is inventorying species and assessing the condition of a coral reef.

Why monitor coral reefs?

US coral reef ecosystems are important and complex resources in terms of biological diversity, fisheries production, coastal protection, tourism, maritime and cultural heritage, and local sustenance. Reef ecosystems include not only the reef structure itself, but also the diverse wildlife that utilize reef habitat for food and shelter, as well as the interdependent habitats, such as seagrass beds, water column (plankton), soft bottom, and mangroves.

Coral reef ecosystems are under stress from both natural events (e.g., hurricanes and tropical storms) and human activities (e.g., tourism, fishing, and dredging). A recent World Resources Institute report estimated that nearly 60% of the world's reefs are threatened by human activity. The International Coral Reef Initiative estimated that 10% of all reefs have been degraded beyond recovery and another 20-30% will be in peril over the next 10 to 20 years.

The cause of some damage is obvious, as when a ship runs aground or a hurricane strikes a shallow reef. Other causes are more insidious, and may slowly change the abundance, community structure, diversity, and condition of reef organisms. Global climate change can lead to changes in atmospheric CO_2, solar irradiance, sea surface temperature (SST), sea level, and other environmental features of critical importance to coral reefs. For example, over the last two decades widespread and prolonged summertime SST anomalies have led to: coral bleaching; mass mortality of reef-building corals, fish, and many other invertebrates associated with reef structures; and increased frequency and variety of coral diseases. Therefore, chronic pollution, increased nutrients, salinity, CO_2, and temperature must be monitored to understand and to anticipate biological changes in reefs.

On June 11, 1998, President Clinton signed Executive Order 13089 "Coral Reef Protection" to conserve and protect US coral reef ecosystems. The US Coral Reef Task Force (USCRTF) was established to implement this Order. Soon after, six working groups with representatives from Federal, State, Commonwealth, and Territorial agencies were created to respond in the areas of: 1) Coastal Uses, 2) Ecosystem Science and Conservation, 3) Mapping and Information Synthesis, 4) Water and Air Quality, 5) International Dimensions, and 6) Education and Outreach.

Endorsed by all Working Groups, this Program will be both national and comprehensive in scope, providing a single focus for USCRTF assessment and monitoring issues. Additionally, the USCRTF adopted the *1999 U.S. All Islands Coral Reef Initiative Strategy* or "Green Book" prepared by the US All Islands Coral Reef Initiative Coordinating Committee. Thus, Green Book initiatives relevant to coral reef ecosystem assessment and monitoring will be part of this program. Another requirement in the President's Executive Order was that this program address the assessment of coral reefs and the preparation of USCRTF biennial reports on the status and trends of US coral reef ecosystems.

The declining state of coral reef ecosystems and another recent global coral reef bleaching episode has sparked international concern among scientists, managers, governmental officials, and the public. The 1991 US sponsored workshop on coral bleaching, coral reef ecosystems, and global climate change; the 1992 Seventh International Coral Reef Symposium, in Guam; and the 1993 meeting of experts on *Global Aspects of Coral Reefs: Health Hazards and History* held at the Rosenstiel School of Marine and Atmospheric Science in Miami, all focused on coral reef concerns. Recognizing the seriousness of the problem, the International Oceanographic Commission, the United Nations Environmental Program, and the International Union for the Conservation of Nature established the International Coral Reef Initiative (ICRI) for participant nations to share information on the status of coral reefs through its Global Coral Reef Monitoring Network (GCRMN). Although the United States was a major catalyst in the formation of ICRI, the lack of a national monitoring program means that any US input to GCRMN has been piecemeal. This new Program will allow, for the first time, full US participation in this global monitoring effort.

These divers are trying to save the majority of this brain coral by removing diseased polyps.

What is envisioned?

This comprehensive, multi-agency, long-term (i.e., decadal) Program has committed to working closely with the nation's coral reef resource managers to enhance the collective national capacity to manage US coral reef resources wisely by:

- Building a US coral reef monitoring network that integrates now disparate local and regional data sets into a national database and information management system;
- Where needed, providing grants to collect information on baseline reef characterizations, inventories of coral reef resources, and adding long-term monitoring sites to fill gaps in coverage nationwide; and
- Reporting biennially on the status and trends in reef ecosystem conditions.

The scope of the Program is US-wide (Florida, Texas/Louisiana, Hawaii, Puerto Rico, US Virgin Islands, Guam, American Samoa, Northern Mariana Islands), and also covers the sovereign US islands in the Pacific (Baker, Howland, Jarvis, Johnston, Kingman, Midway, Palmyra, and Wake). Depending on the level of funding, the Program may also be extended to US-affiliated islands in the Pacific (Palau, Federated States of

Micronesia, Marshall Islands) and the wider Caribbean region.

Resource agencies often have limited authorities to act after human-induced (vessel groundings, water/sediment contamination) and natural (hurricanes, global warming) events impact reefs. Resource managers need to be able to provide reliable information on such impacts to our national and international leaders. The Program is envisioned as long-term and with enough rigor statistically to detect changes in reef condition, evaluate such changes, and alert managers when and how fast reefs are deteriorating, indicate possible corrective measures, and document recovery following management actions. The Program may also help evaluate management actions and monitor ecosystem changes after restoration projects.

Vividly marked reef animals, like this lion fish, are often dangerous.

Answers to the following critical questions can be addressed through a focused monitoring program:

- What do non-technical managers need to know in order to make wise decisions regarding <u>sustainable</u> coral reef ecosystem resources?

- What socioeconomic, demographic, and other data need to be gathered in order to assess and monitor reefs and to predict future reef changes?

- What are the social, cultural, and economic costs of reef degradation or loss?

- Have trends been observed in managed reef fish/shellfish species, the aquarium trade, bioprospecting, and offshore aquaculture that can be related to changes in, and threats to, coral reef ecosystems?

- Where degradation has occurred, can multiple anthropogenic stressors be separated from each other or from natural sources? Where degradation and its causes have been identified, what efforts will be needed to mitigate or rectify the degradation?

- What atmospheric and oceanic forces affect the health, stability, and survival of US controlled coral reef ecosystems?

- Can US coral reef ecosystems sustain current fishing harvests? What has been the influence of modified marine zoning regulations and restoration efforts on US coral reef resources? Have protection measures enhanced fish and invertebrate populations, reef community structure and reef diversity?

- Are existing coral reef Marine Protected Areas (MPAs) effective and how can they be improved?

Who needs what results?

Among the critical partners of this Program will be the local, ongoing coral reef assess ment and monitoring programs, volunteers, and community groups throughout US waters. One of the major needs expressed by US coral reef managers at the Managers Workshop in Hawaii in 2000 was for this program to help build the capacity within island agencies and the local community to monitor coral reef ecosystems. Therefore, this program seeks to train and work closely with locals to collect, interpret, publish, and share information relevant to assessing, inventorying, and monitoring their coral reef ecosystems. Further, along with identifying gaps in monitoring coverage, the survey of programs monitoring US coral reefs will reveal those local programs with data sets that would be desirable to include in the national monitoring network. Subsequent negotiations with local managers to link their data sets into the national network might eventually lead to additional site monitoring and a better understanding of these ecosystems US-wide.

New baseline and historical information on changes in coral reef ecosystems is essential for managers, enabling them to better protect, restore, and conserve coral reef resources, and establish new MPAs. Because of their direct use of assessment and monitoring data, coral reef managers were enlisted as partners in designing and implementing the Program. Managers of marine protected areas (MPAs) with coral reef resources in territorial waters should directly benefit from this program. Many of the established US coral reef MPAs are remote Pacific island National Wildlife Refuges (NW Hawaiian Islands, Midway, Johnston, Howland, Jarvis, Baker, and Rose) which lack assessments and monitoring data but are being threatened by unauthorized fishing, derelict fishing gear, and ship groundings and spills. Other coral reef MPAs in the Pacific, Atlantic, and Caribbean are being threatened by overuse and eutrophication (Florida Keys National Marine Sanctuary, St. Croix and Key Biscayne National Parks, State of Hawaii MPAs, etc.).

In a broader sense, the scientific community will be an important user of data from the Program. The Program's data and GIS-based information system will be purposely designed to make all data, analyses, and reports easily accessible. The Program will compile a very large volume of data that will be used by many scientists and other professionals to research a wide variety of questions.

Finally, the user community for Program information goes beyond scientists and resource managers, and includes the fishing and aquaculture industries, the dive and ecotourism industries, and the owners of restaurants, hotels, and other infrastructure that support coral reef users. Care will be taken that the information provided by the Program does not, in turn, increase management problems for the reefs being monitored, such as the exploitation of undiscovered reefs found to have abundant biotic resources.

Reef currents carry plankton to sessile benthic filterfeeders.

What will be produced?

The Program will yield a number of outcomes and products that will play critical roles in the assessment, management, and restoration of US reefs:

- A national Coral Reef Data and Information Management System that will provide user-friendly, integrated access to disparate coral reef ecosystem data sets, including still and video photography. The system will be web-enabled, easy to query and sort, and able to map complex ecosystem information.

- A fully functioning, long-term monitoring network for MPAs and other US coral reefs.

- A management-driven approach for identifying sites that require assessment of baseline ecological and population conditions and more intensive monitoring of biological, chemical, physical, geological, and socioeconomical components of coral reef ecosystems.

- The data needed by resource managers to assess reef impacts (e.g. water quality, sedimentation, physical reef damage, overfishing), and to improve management, protection, and preservation of US coral reef ecosystems.

- National assessments of the status and trends in US coral reef ecosystems.

Monitoring species diversity is often used to evaluate the success of reef management.

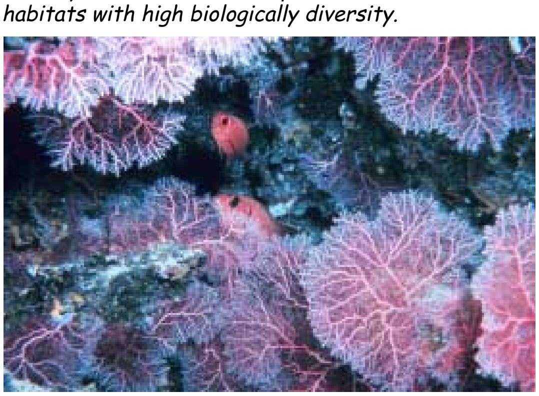
When will this happen?

The envisioned Program will be phased-in over a two-year period with “full” implementation by FY2002. This national program document, along with its 5-year implementation plan, will be available to the public by autumn 2000. Since the Program will be multi-agency sponsored (i.e., dependent on available Federal, State, Commonwealth, and Territorial coordination and funding), phased in over several years, and built upon local and regional monitoring already underway, start-up and maintenance costs will be considerably less than what might be presumed for a “new” national program. Priority projects, in keeping with available funding, will be determined each year in consultation with coral reef managers and scientists. Priorities for 2001-2002 will be set in consultation with the nation’s coral reef managers, scientists, leaders of regional volunteer monitoring programs, and the concerned public.

Notwithstanding such considerations, established coral reef MPAs will be assessed nationwide and targeted for monitoring by virtue of their status. Priority will be given those MPAs for which there is little scien tific data (remote Pacific islands) and other MPAs near population centers where anthropogenic stress is concentrated. Intensive monitoring will be targeted at certain reefs to assess the effectiveness of specific management actions, including the role of MPAs in the recovery of reefs. Data will be collected at a series of reference sites. Selection of these sites will address the needs of managers and conform to appropriate and consistent sampling designs. Thanks to an FY2000 congressional appropriation to NOAA, the following actions are well underway:

- ***An inventory/survey of existing local, regional, and international monitoring programs.*** One of the initial activities of this program is an inventory of ongoing monitoring projects. The manager or principal investigator responsible for each identified program will be asked to volunteer further information such as programmatic goals, scope, and geographic coverage. Based on this inventory, gaps will be identified to determine where baseline characterization and increased monitoring coverage are needed and which programs will feed directly into the monitoring network.

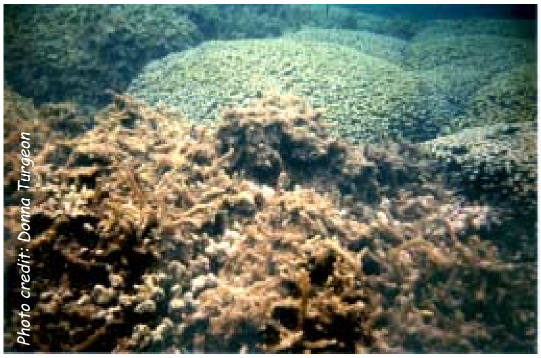
Healthy coral reefs are complex, three-dimensional habitats with high biologically diversity.



- ***An initial FY2000 report on the status of US coral reef ecosystems.*** State and territorial scientists and managers will prepare reports by August of 2000 on the condition of their coral reef resources. These will be the basis for an initial national report on the status of US coral reef ecosystems that will also serve as the US input to the *Global State of the Reefs,* a report to be issued in 2000 by the GCRMN.

- ***A data management and information system with GIS-based mapping and querying capability.*** A small team is conducting a needs assessment and designing a virtual data center and national monitoring network. NOAA's web site will be the portal for this information with links to other important sites related to coral reef monitoring. Designing and building a system that will link to local monitoring data sets will require the hiring of at least one full time employee, along with support for those programs linking to the national network.

- ***An implementation plan for a nationally coordinated, comprehensive, long-term program that builds on and ensures continued support for local and regional monitoring programs.*** An initial working group of about 50 experts, which included at least one representative from the six Coral Reef Task Force Working Groups and the All Island

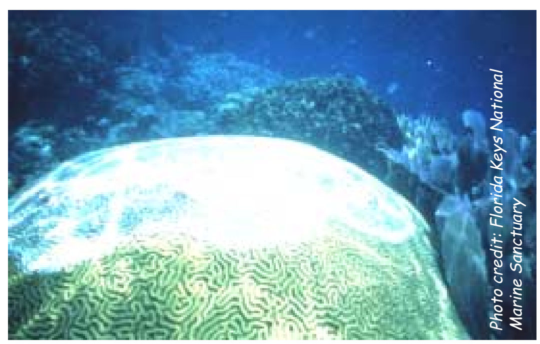


One of many invasive species, these algae are overgrowing and killing coral colonies.

Coral Reef Initiative Coordinating Committee, designed an interagency program to assess and monitor US coral reef ecosystems. After clearance through all of the US Coral Reef Task Force (USCRTF) Working Groups, the draft Plan was endorsed by the USCRTF in November 1999.

During February 2000, a workshop was convened to solicit input on the draft Program document and its implementation plan from the greater coral reef community, especially the managers of ongoing agency monitoring programs and the managers of marine protected areas (Sanctuaries, Refuges, and Parks). Sponsored by the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) and the Department of the Interior's National Park Service, the workshop, with 60 attendees, was held in Hawaii on February 10-11, 2000. At this workshop, coral reef program managers commented on a draft version of the programmatic document and made recommendations for developing the implementation plan. This workshop was critical to the development of an implementation plan that recognizes the differences in reef ecology between the Pacific and Atlantic/Caribbean regions and meets the needs of regional managers and scientists. All contributors to the development of the draft program plan have been afforded the opportunity to comment on the final *Implementation Plan for A National Program to Assess, Inventory, and Monitor US Coral Reef Ecosystems*. Program implementation in 2000 has become a reality through new Congressional appropriations to the Departments of Commerce and Interior that have been directed toward funding USCRTF mapping, monitoring, and management of US coral reefs. To realize all that has been envisioned for this program, reverse the degradation of our nation's coral reef ecosystems, and sustain the wise stewardship of reef resources, the partnership agencies need to continue their commitment to jointly conduct and support this program.

A world-wide problem, bleaching can result in the death of entire coral colonies.



Marine debris can have a major impact on coral and other reef animals.

A NATIONAL PROGRAM TO
ASSESS, INVENTORY, AND MONITOR CORAL REEF ECOSYSTEMS

OBJECTIVES

Responsible for interagency leadership and program oversight, the NCCOS Biogeography Program coordinates *A National Program to Assess, Inventory, and Monitor Coral Reef Ecosystems* and assures that the following Key Conservation Objectives from the US Coral Reef Task Force *National Action Plan to Conserve Coral Reefs* are met:

- Working closely with partners and stakeholders, develop and implement a nationally coordinated, long-term program to assess, inventory, and monitor US coral reef ecosystems.
- Develop a web-enabled data management and information system for US reef monitoring and mapping data, with user-friendly GIS-based mapping and querying capability to present complex information in usable formats to all potential users, while ensuring the security of sensitive place-based biological or cultural resource data.
- Prepare biennial reports on the *State of US Coral Reef Ecosystems.*

DESCRIPTION

Working closely with hundreds of partners and stakeholders, this program was designed in 1999 and implemented in 2000. It is endorsed by the US Coral Reef Task Force and a priority in the *National Action Plan to Conserve Coral Reefs*. NOS is the primary funding agency through Congressional FY2000-01 appropriations for coral reef conservation, and other NOAA appropriations relevant to coral reef monitoring. The current scope of work is comprised of six interagency tasks that must be integrated to meet the above national objectives:

- **Task 1.** Administer cooperative grants to States, territories, and commonwealths that build local capacity for long-term monitoring while filling gaps in the National Coral Reef Monitoring Network.
- **Task 2.** Maintain an easy-to-query GIS that displays up-do-date information on US coral reef ecosystem assessments and monitoring as a gap-analysis tool for resource managers.
- **Task 3.** Build an NCCOS coral reef mapping and monitoring database with a web-enabled, GIS capability to download and map the latest coral reef resource information.
- **Task 4.** Create a website for the National Coral Reef Monitoring Network, Database, and Information Management System—a single-access NOAA portal that links information on coral reef ecosystem maps, assessments, inventories, and monitoring nationwide.
- **Task 5.** Design a "report card" based on indicators of coral reef condition that will be a reliable tool for predicting changes in coral reef ecosystems and reporting to the public.
- **Task 6.** Convene a national workshop for agency partners and managers of monitoring programs to prioritize their needs relevant to the 1) National Coral Reef Monitoring Network and Database and Information Management System, 2) report card indicators to track and predict coral reef condition, 3) draft biennial report on *The State of US Coral Reef Ecosystems*, and 4) initial accomplishments, products, and future activities of *A National Program to Assess, Inventory, and Monitor Coral Reef Ecosystems*Placeholder for “A National Program to Assess, Inventory, and Monitor U.S. Coral Reefs”

FY01 CCMA's BIOGEOGRAPHY PROGRAM
PROPOSED PROJECT DESCRIPTION

PROJECT TITLE & STATUS

National Program to Assess, Inventory, and Monitor Coral Reef Ecosystems

INTRODUCTION/RATIONALE Through Executive Order 13089, the US Coral Reef Task Force (USCRTF) is charged with coordinating a comprehensive program to map and monitor US coral reefs. The USCRTF's *National Action Plan to Conserve Coral Reefs* lays out a science-based road map to healthy coral reefs for generations to come, and places "high priority on the establishment of a nationally coordinated, long-term monitoring program for US coral reefs." The Center for Coastal Monitoring and Assessment's (CCMA) Biogeography Program (BP) coordinates *A National Program to Assess, Inventory, and Monitor Coral Reef Ecosystems.* To help guide the development of this program, CCMA convened the Task Force Working Group for Coral Reef Assessment and Monitoring, continues to periodically consult with this body of experts, and works closely with its State, territory, commonwealth and local government partners to implement the Program.

OBJECTIVES

Responsible for interagency leadership and program oversight, BP assures the following Task Force National Plan Key Conservation Objectives are met:

- Working closely with partners and stakeholders, develop and implement a nationally coordinated, long-term program to assess, inventory, and monitor US coral reef ecosystems.
- Develop a web-enabled data management and information system for US reef monitoring and mapping data, with user-friendly GIS-based mapping and querying capability to present complex information in usable formats to all potential users, while ensuring the security of sensitive place-based biological or cultural resource data.
- Prepare biennial reports on the *State of US Coral Reef Ecosystems.*

APPROACH

The current scope of work is comprised of six interagency tasks that must be integrated to meet the above objectives:

- **Task 1.** Administer FY2000 and award FY2001 cooperative grants to States, territories, and commonwealths for them to build local capacity for long-term monitoring and begin to fill gaps in the National Monitoring Network.
- **Task 2.** Continue to develop a national database on coral reef monitoring sites based on metadata gathered by the US Coral Reef Monitoring Project Survey. Together with program partners, continue to refine the accuracy and completeness of an easy-to-query GIS, which maps the latest information on coral reef assessments and monitoring being conducted nationwide as a gap-analysis tool for resource managers. Currently, users can obtain information on a total of 3,248 data points representing individual monitoring sites and areas. These sites are electronically linked to information on who is conducting the monitoring project, what parameters are sampled, how frequently has sampling occurred, and the period of record over which monitoring has been conducted.
- **Task 3.** Begin to build an NOS/NCCOS coral reef mapping and monitoring database (i.e., for new coral reef ecosystem mapping, assessments, inventories, and monitoring data, including NCCOS-administered grants to States and Territories) with an easy-to-query web-enabled, GIS capability. This national database will be the framework for the real-time Coral Reef

National Monitoring Network, Database, and Information System (NCRDIMS), see Task 4). When fully implemented, the System will link now-disparate local, regional, and national monitoring data with the NCCOS database/GIS so that coral reef managers will have ready access to science-based tools for decisionmaking. This initiative is 1) recommended by the nation's coral reef managers, 2) a priority in the *National Action Plan to Conserve Coral Reefs*, and 3) detailed more fully in A National Program to Assess, Inventory, and Monitor Coral Reef Ecosystems.

- **Task 4.** Closely linked with the previous task, serve on and guide the NOAA database management team that will develop the NOAA single access portal for its coral reef information, and design the website for the National Coral Reef Monitoring Network, Database, and Information Management System.
- **Task 5.** Begin the development of a "report card" based on indicator metrics of coral reef condition that can predict changes in this ecosystem and will be a reliable tool for reporting to the nation. Even though the report card will not be fully operational this year, incorporate any pieces that may be ready in time for inclusion in the *State of US Coral Reef Ecosystems* first biennial report to test efficacy and request comments from its readership.
- **Task 6.** Convene a national workshop for agency partners and managers of monitoring programs to assess their needs for, make recommendations on, and evaluate utility of the 1) National Coral Reef Monitoring Network and Information Management System, 2) biennial reports on the *State of US Coral Reef Ecosystems* based on a national report card for tracking and predicting coral reef condition, and 3) National Program initial accomplishments, products, and future direction.

DELIVERABLE PRODUCTS

Task 1 service and deliverables:

- Client-oriented service focused on assisting coral reef grant awardees (State, Territorial, and Commonwealth resource managers) in the preparation of proposals and reports, resolving grant-related issues, facilitating peer-reviews of awards by recognized experts, and assuring the day-to-day administration of coral reef monitoring grants.
- National guidelines for standardized methods, protocols, and reporting formats for assessment and monitoring data. Data comparability among monitoring sites is essential to building a Coral Reef National Monitoring Network and Mapping Database and Information System that can be used to prepare reliable assessments on the condition of American coral reef ecosystems and predict changes in coral reef ecosystems nationwide.

Task 2 service and deliverables:

- A current and comprehensive database containing metadata from monitoring and assessment programs/projects nationwide. This database will be accompanied by a user's guidance manual and NOS/NCCOS point of contact for assistance with problems.
- An easy-to-query, web-based gap-analysis tool for coral reef managers, which will use GIS maps to display the locations of coral reef ecosystem monitoring sites along with linked information on parameters monitored at each site.
- A technical report analyzing the results of the US Coral Reef Monitoring Program Survey, which will detect geographic gaps and clusters in coral reef parameters and methods used by US coral reef monitoring and assessment programs/projects.

Task 3 service and deliverables:

- A national coral reef mapping and monitoring database with web-enabled, GIS mapping and querying capability for resource managers to download data and map monitoring information.
- State-of-the-art maps of national coral reef resources accessible to users.

Task 4 service and deliverables:

- A series of design documents for the NCRDIMS, including 1) system requirements; 2) customer, users, and constituents needs and requirements; 3) an information technology architecture proposal based on the first two documents; 4) a review of functionalities of existing coral reef systems within NOAA, 5) a coral reef data archive and preservation plan, and 6) an outline project plan, approach, and required resources.
- A single portal of web entry on the NOAA home page (one-stop shopping at NOAA) for the coral reef community to obtain interagency coral reef monitoring and mapping data, map products displaying coral reef habitats and species, biennial reports on the *State of US Coral Reef Ecosystems*, linkages to ongoing coral reef monitoring programs, and more.

Task 5 service and deliverables:

- A determination of what is essential to know about coral reef ecosystem condition and a proposed coral reef condition index (a proposed set of indicators with one or more metrics to measure a particular aspect of the overall indicator).
- An NCCOS-facilitated report to the public—*State of US Coral Reef Ecosystems*—will be issued biennially. This report will be a national assessment of coral reef ecosystem condition index (a "report card" of indicators, each with one or more metrics), and based on regional assessments of the condition of US coral reef ecosystems (Florida, Texas, Puerto Rico, the US Virgin Islands, Navassa, Hawaii, American Samoa, Guam, the Commonwealth of the Northern Mariana Islands, and US-affiliated Pacific Islands).

Task 6 service and deliverables:

- Pre-workshop documents mailed to managers include 1) managers' needs matrices/statements for coral reef assessments/monitoring activities by jurisdiction, and the National Coral Reef Monitoring Network and Database and Information Management System; 2) web-based gap analysis tool for coral reef managers to know what and where coral reef ecosystem monitoring is being conducted around the nation; 3) proposed coral reef condition index indicators and metrics for biennial reports; 4) proposed guidelines for standardized methods, protocols, and reporting formats for the National Monitoring Network; and 5) programmatic accomplishments and initial products for their review.
- A post-workshop summary of findings, prioritized managers' needs matrices, and programmatic recommendations.

MILESTONES & TIME SCHEDULES

This is a long-term interagency science program to assess and monitor US coral reef ecosystems, that is coordinated by NOS/NCCOS and has been endorsed by the US Coral Reef Task Force. Working closely with a large cadre of partners and stakeholders, this program was designed in 1999 and implementted in 2000. The above tasks are planned to be conducted in 2001.

Task 1. FY 2000 semiannual reports due by April; FY 2001 grants to be awarded by September 31; proposed guidelines for standardized methods and protocols by September 31.

Task 2. Current and comprehensive database ongoing; prototype web-based gap analysis tool for coral reef managers ready in time for Task 6 workshop; technical report ready by September 31.

Task 3. An NOS/NCCOS coral reef monitoring and mapping database is being developed that will remain an ongoing activity of this program; coral reef habitat maps that will be the basis for coral reef assessments and monitoring will be completed for the US Virgin Islands in July 31, for Puerto Rico by September 31.

Task 4. The design documents need to be ready by the time the Task 6's workshop is convened; the website should be functional by September 31; the interagency National Monitoring Network and National Database and Information Management System will continue to be built over the next few years.

Task 5. Proposed indicators, metrics, and the initial biennial report is due by September 31.

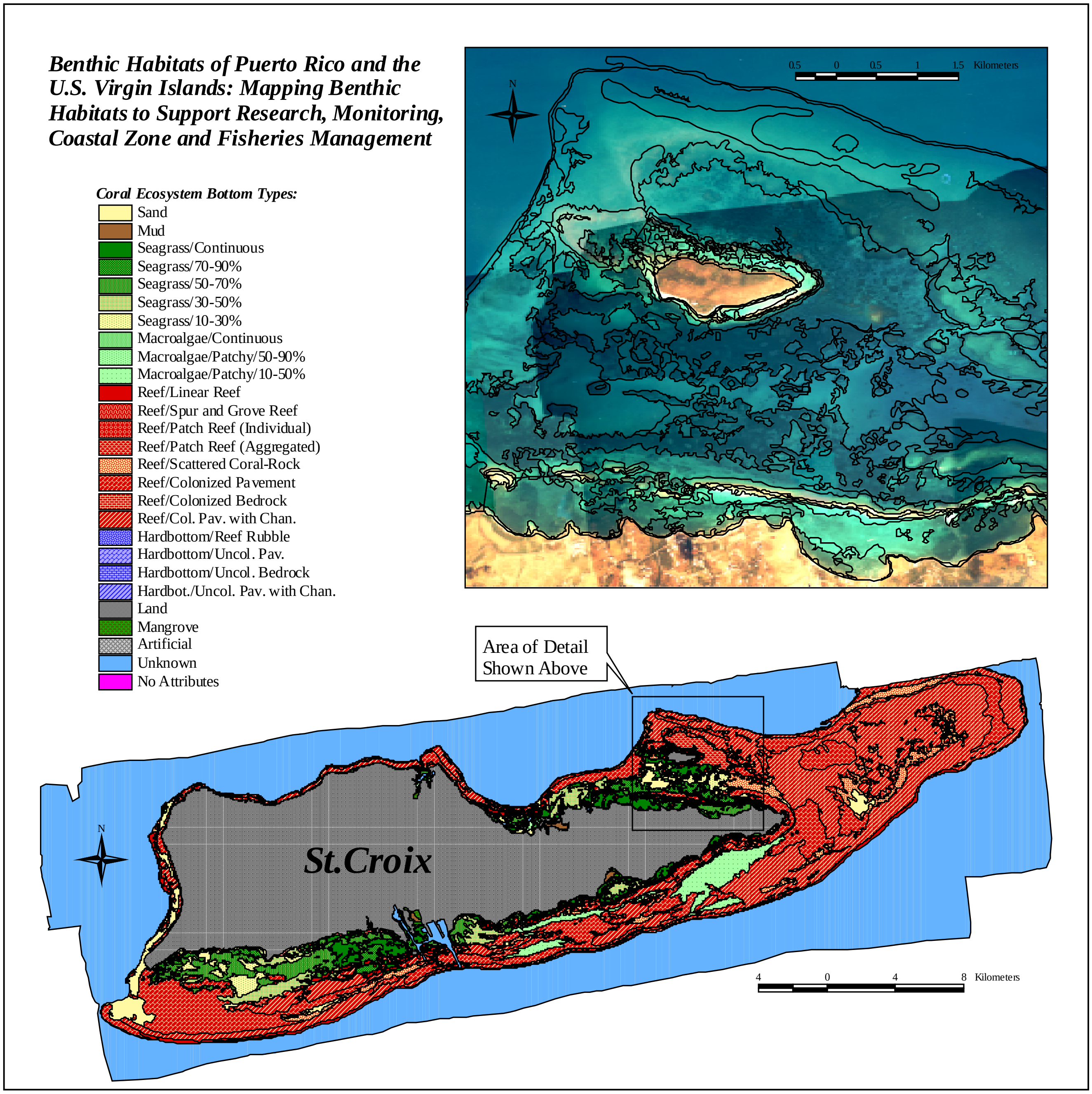
Task 6. The national workshop will be convened by September 31.

RELATION TO NOS/CCMA ACTIVITIES

This interagency program has many partners and a large supportive constituency. Endorsed by the US Coral Reef Task Force, long-term program implementation is a priority of the *National Action Plan to Conserve Coral Reefs*. Funding has been primarily through NOS FY2000-01 Congressional appropriation for coral reef conservation, and other agency funding for coral reef monitoring and related activities.

Benthic Habitats of Puerto Rico and the U.S. Virgin Islands: Mapping Benthic Habitats to Support Research, Monitoring, Coastal Zone and Fisheries Management

The Center for Coastal Monitoring and Assessment's (CCMA) Biogeography Program (BP) has completed a collaborative project to map the distribution of marine habitats in the U.S. Virgin Islands using visual interpretation of aerial photos. NOAA's National Geodetic Survey (NGS) acquired aerial photographs for the nearshore waters of these islands in 1999. These images were used to create maps of the region's coral reefs, seagrass beds, mangrove forests, and other important habitats for fisheries, tourism, and other aspects of the coastal economy. Accurate habitat maps are necessary for resource managers to make informed decisions about the protection and use of these areas. The primary product of this project is the benthic habitat map. However, to supplement maps, digital scans of the original aerial photographs, georeferenced mosaics, a GIS mapping tool for use with ArcView, a detailed explanation of methodology, and supporting data sets are also provided. Twenty-six distinct benthic habitat types within nine zones were mapped. The deliverables from this project represent major improvements in the natural resources inventory and management tools for these islands since maps of this type do not currently exist.



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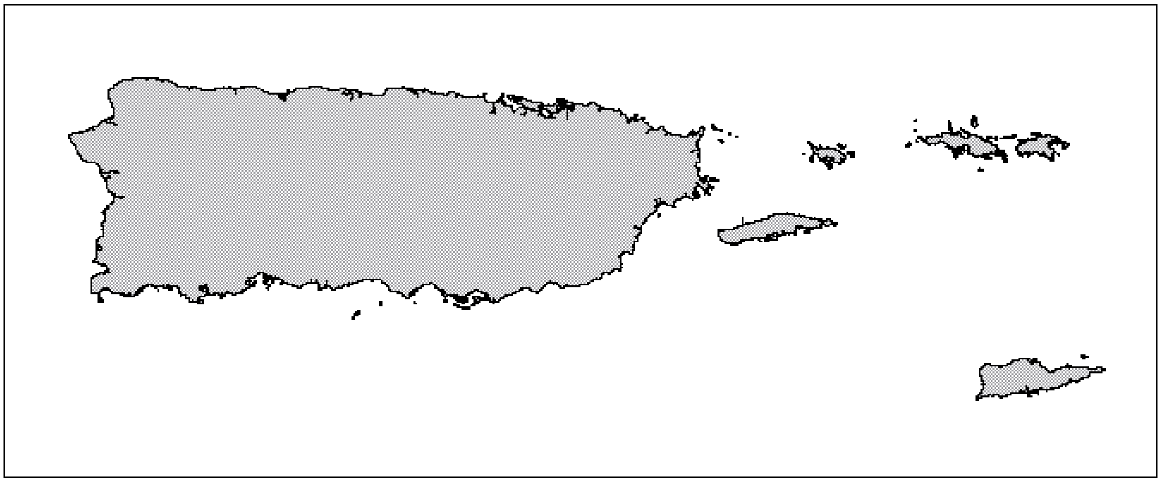
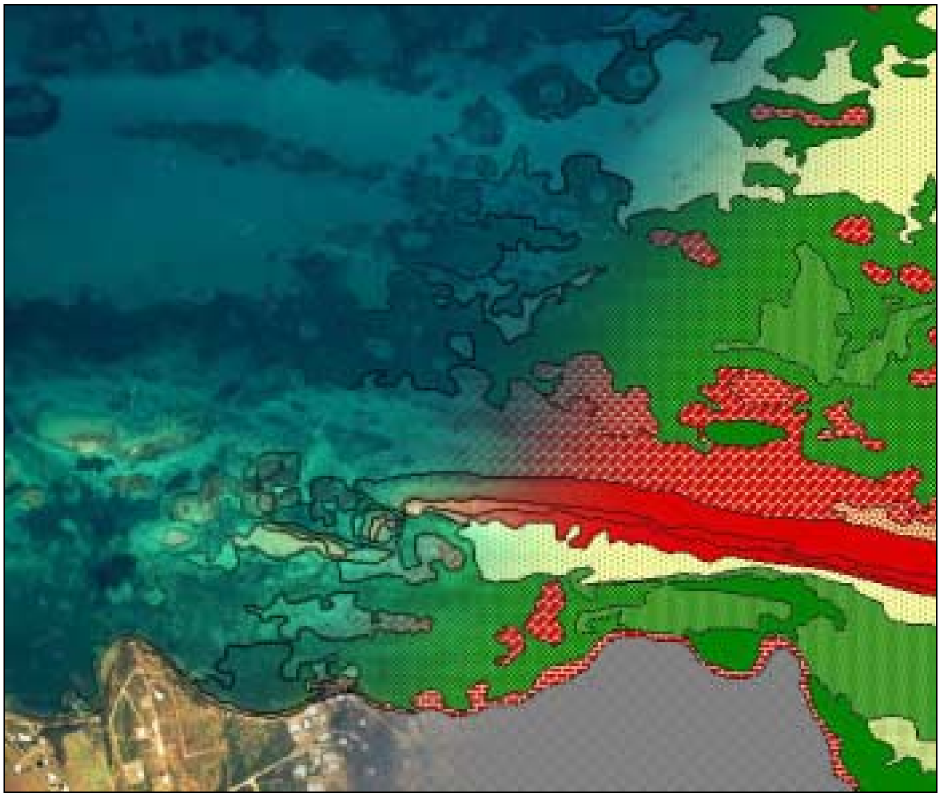
Benthic Habitats of Puerto Rico and the U.S. Virgin Islands:



Project Methods



Kendall, M.S.[1], C.R. Kruer[2], K. R. Buja[1], J.D. Christensen[1], M. Finkbeiner[3], and M.E.Monaco[1]

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3. *NOAA, Coastal Services Center, 2234 South Hobson Avenue; Charleston, SC 29405*

Project Overview:

NOAA's National Ocean Service (NOS) and National Geodetic Survey (NGS) acquired aerial photographs for the nearshore waters of Puerto Rico and the U.S. Virgin Islands in 1999. These images have been used to create maps of the region's coral reefs, seagrass beds, mangrove forests, and other important habitats for fisheries, tourism, and other aspects of the coastal economy. Accurate habitat maps are necessary for resource managers to make informed decisions about the protection and use of these areas. The primary product of this project is a benthic habitat map. However, to supplement maps, digital scans of the original aerial photographs, georeferenced mosaics, a GIS mapping tool for use with ArcView, a detailed explanation of methodology, and supporting data sets are also provided.

Developing the Habitat Classification Scheme

A hierarchical classification scheme was used to define and delineate habitats. The classification scheme was influenced by many factors including: requests of the management community, existing classification schemes for coastal ecosystems in Puerto Rico (Kruer, 1995; Reid and Kruer, 1998; Lindeman *et al*,1998), the Virgin Islands (Conservation Data Center; Beets *et al*, 1986; Boulon, 1986), other coral reef systems (Holthus and Maragos, 1995; Shepard et al., 1995; Vierros, 1997; Chauvaud et al, 1998; Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute and NOAA, 1998; Mumby et al,1998; NOAA et al, 1998), quantitative habitat data for Puerto Rico and the Virgin Islands, the minimum mapping unit (MMU; 1 acre for visual photointerpretation), and analysis of the spatial and spectral limitations of the scanned aerial photographs. The scheme is hierarchical to allow users to expand or collapse the detail of the resulting map to suit their needs. Furthermore, it is encouraged that additional hierarchical categories be added in the GIS by users with more detailed knowledge or data for specific areas. For example, habitat polygons delineated as continuous seagrass using this scheme could be further categorized with standing crop information (low, medium, or high shoot density) or species composition (*Thalassia*, *Syringodium*).

General Description of the Classification Scheme

The classification scheme defines benthic communities on the basis of two attributes: large geographic “zones” which are composed of smaller “habitats”. Zone refers only to benthic community location and habitat refers only to substrate and/or cover type. Every polygon on the benthic community map will be assigned a habitat within a zone (e.g. sand in the lagoon, or sand on the bank). Zone indicates polygon location and habitat indicates composition of each benthic community delineated. Combinations of habitat and zone that are analogous to traditionally used terminology are noted where appropriate. The description of each zone and habitat includes example images. Underwater as well as aerial photographs are included for habitats, whereas only aerial images are included for zones. The zone/habitat approach to the classification scheme was developed by the Caribbean Fishery Management Council; Dr. Ken Lindeman, Environmental Defense; and the NOS Biogeography Team.

Nine mutually exclusive zones were identified from land to open water corresponding to typical insular shelf and coral reef geomorphology. These zones include: land, shoreline/intertidal, lagoon, backreef, reef crest, forereef, bank/shelf, bank/shelf escarpment, and dredged (since this condition eliminates natural geomorphology). Zone refers only to each benthic community’s location and does not address substrate or cover types within. For example, the lagoon zone may include patch reefs, sand, and seagrass beds, however, these are considered structural elements that may or may not occur within the lagoon zone and therefore, are not used to define it.

Twenty-six distinct and non-overlapping habitat types were identified that could be mapped by visual photointerpretation. Habitats or features that cover areas smaller than the MMU were not considered. For example, sand halos surrounding patch reefs are too small to be mapped independently. Habitat refers only to each benthic community’s substrate and/or cover type and does not address location on the shelf. Habitats are defined in a collapsible hierarchy ranging from four broad classes (Submerged Vegetation, Unconsolidated Sediment, Coral Reef/Hardbottom, and Other), to more detailed categories (e.g. mangrove, seagrass, algae, individual patch reefs, bedrock, etc.), to patchiness of some specific features (e.g. 50-70% cover of seagrass).

Zones:

Land
Shoreline Intertidal
Lagoon
Back Reef
Reef Crest
Fore Reef
Bank/Shelf
Bank/Shelf Escarpment
Dredged*
Unknown

Figure 1. Cross-section of *Zones* where an emergent reef crest is present:

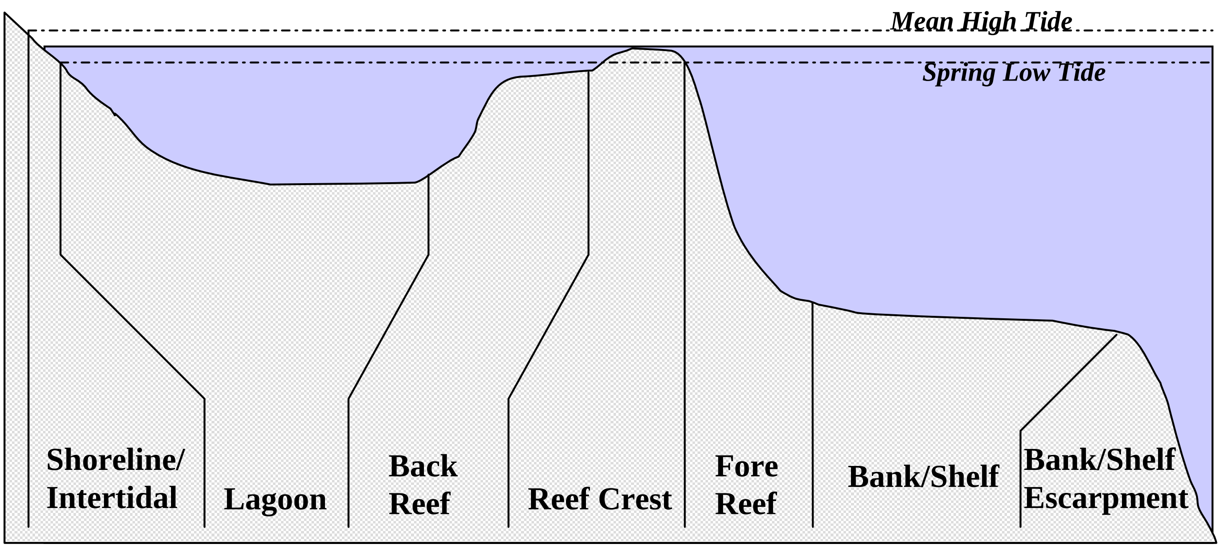
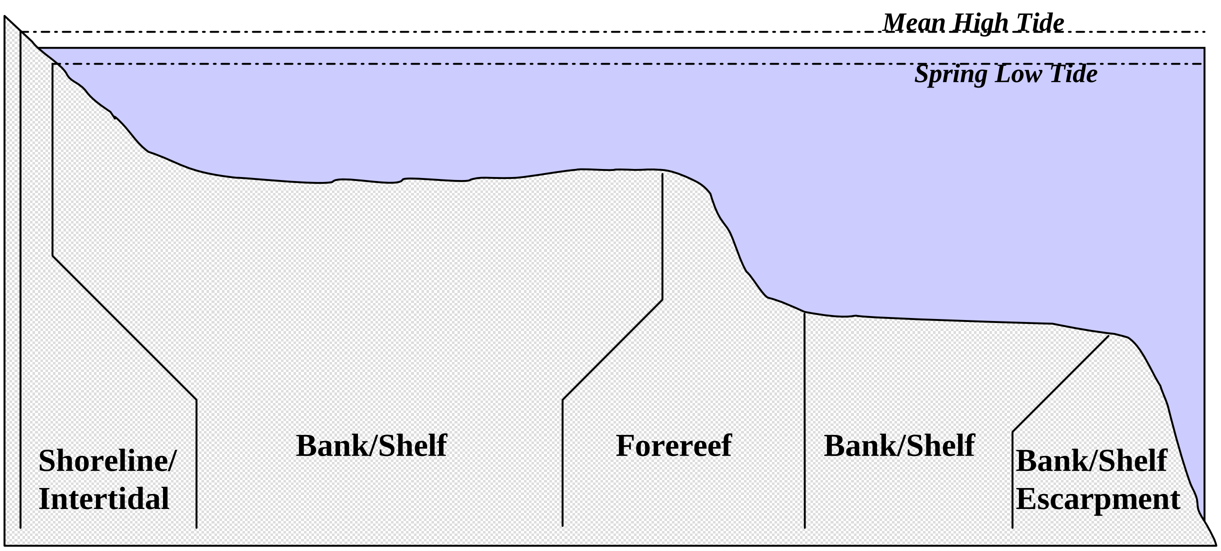


Figure 2. Cross-section of *Zones* where NO emergent reef crest is present:



***not depicted in figures**

Habitats:

Unconsolidated Sediments (0%-<10% submerged vegetation)

- **Sand**
- **Mud**

Submerged Vegetation

- **Seagrass**
  - **Continuous Seagrass (90%-100% Cover)**
  - **Patchy (Discontinuous) Seagrass (70%-<90% Cover)**
  - **Patchy (Discontinuous) Seagrass (50%-<70% Cover)**
  - **Patchy (Discontinuous) Seagrass (30%-<50% Cover)**
  - **Patchy (Discontinuous) Seagrass (10%-<30% Cover)**
- **Macroalgae**
  - **Continuous Macroalgae (90%-100% Cover)**
  - **Patchy (Discontinuous) Macroalgae (50%-<90% Cover)**
  - **Patchy (Discontinuous) Macroalgae (10%-<50% Cover)**

Coral Reef and Hardbottom

- **Coral Reef and Colonized Hardbottom**
  - **Linear Reef**
  - **Spur and Groove**
  - **Individual Patch Reef**
  - **Aggregated Patch Reefs**
  - **Scattered Coral/Rock in Unconsolidated Sediment**
  - **Colonized Pavement**
  - **Colonized Bedrock**
  - **Colonized Pavement with Sand Channels**
- **Uncolonized Hardbottom**
  - **Reef Rubble**
  - **Uncolonized Pavement**
  - **Uncolonized Bedrock**
  - **Uncolonized Pavement with Sand Channels**

Other Delineations

- **Land**
- **Mangrove**
- **Artificial**
- **Unknown**

Zones

Shoreline Intertidal: Area between the mean high water line (or landward edge of mangroves when they are present) and lowest spring tide level (does not include emergent segments of barrier reefs). Typically, this zone is narrow due to the small tidal range in this part of the Caribbean.

Typical Habitats: Mangrove, sand, seagrass, colonized bedrock, and uncolonized bedrock.

Lagoon: Shallow area (relative to the deeper water of the bank/shelf) between the shoreline intertidal zone and the back reef of a reef or a barrier island. This zone is protected from the high-energy waves commonly experienced on the bank/shelf and reef crest. If no reef crest is present, there is no lagoon zone.

Typical Habitats: Sand, seagrass, algae, pavement, bedrock, and patch reefs.

Back Reef: Area between the seaward edge of a lagoon floor and the landward edge of a reef crest. This zone is only present when a reef crest exists.

Typical Habitats: Sand, reef rubble, seagrass, algae, linear reef, and patch reef.

Reef Crest: The flattened, emergent (especially during low tides) or nearly emergent segment of a reef. This zone lies between the back reef and fore reef zones. Breaking waves will often be visible in aerial images at the seaward edge of this zone.

Typical Habitats: Reef rubble, algal ridge, and linear reef.

Fore Reef: Area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform. Features not forming an emergent reef crest but still having a seaward-facing slope that is significantly greater than the slope of the bank/shelf are also designated as fore reef (fig.2).

Typical Habitats: Linear reef and spur and groove.

Bank/Shelf: Deep water area (relative to the shallow water in a lagoon) extending offshore from the seaward edge of the fore reef to the beginning of the escarpment where the insular shelf drops off into deep, oceanic water. The Bank/Shelf is the flattened platform between the fore reef and deep open ocean waters or between the shoreline/intertidal zone and open ocean if no reef crest is present.

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Typical Habitats: Sand, patch reefs, algae, seagrass, linear reef, colonized and uncolonized pavement, colonized and uncolonized pavement with sand channels, and other coral reef habitats

Bank/Shelf Escarpment: The edge of the bank/shelf where depth increases rapidly into deep, oceanic water. This zone begins at approximately 20 to 30 meters deep, near the depth limit of features visible in aerial images. This zone extends well into depths exceeding those that can be seen on aerial photos and is intended to capture the transition from the bank/shelf to deep waters of the open ocean.

Typical Habitats: Sand, linear reef, and spur and groove.

Unknown: Zone uninterpretable due to turbidity, cloud cover, water depth, or other interference.

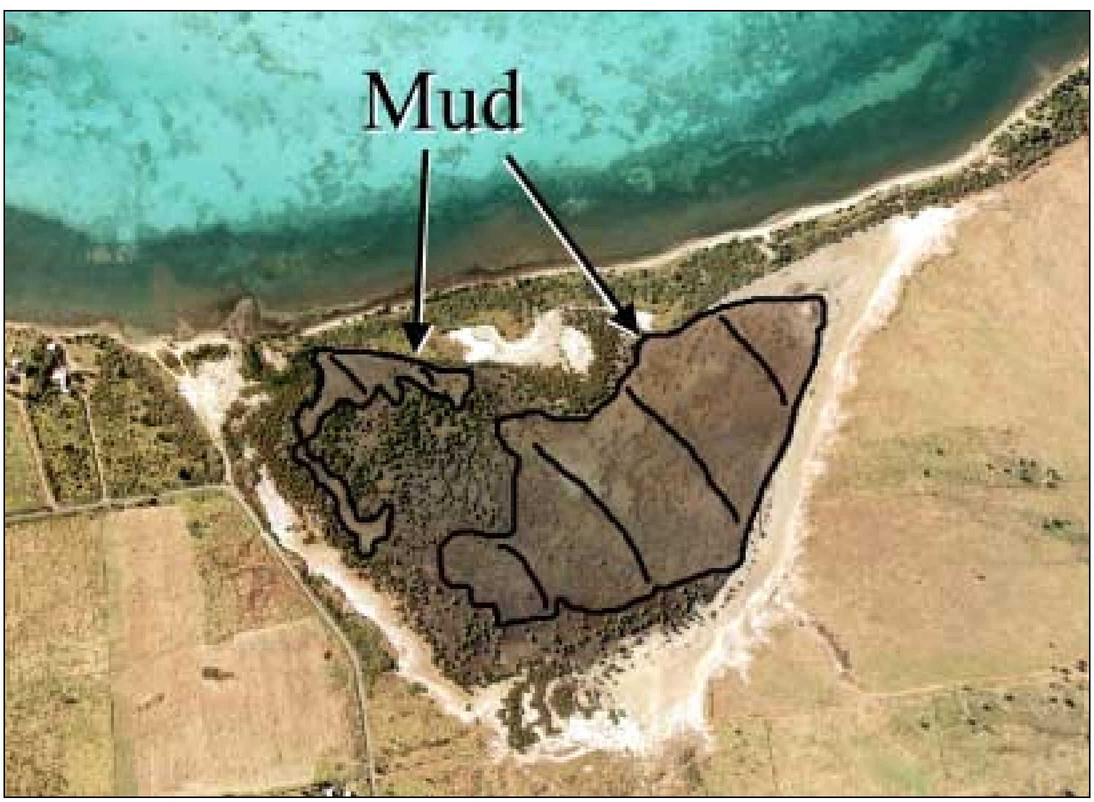
Dredged: Excavated or dredged areas that have natural geomorphology disrupted or altered.

Typical Habitats: Sand, mud, seagrass, or algal bottom.

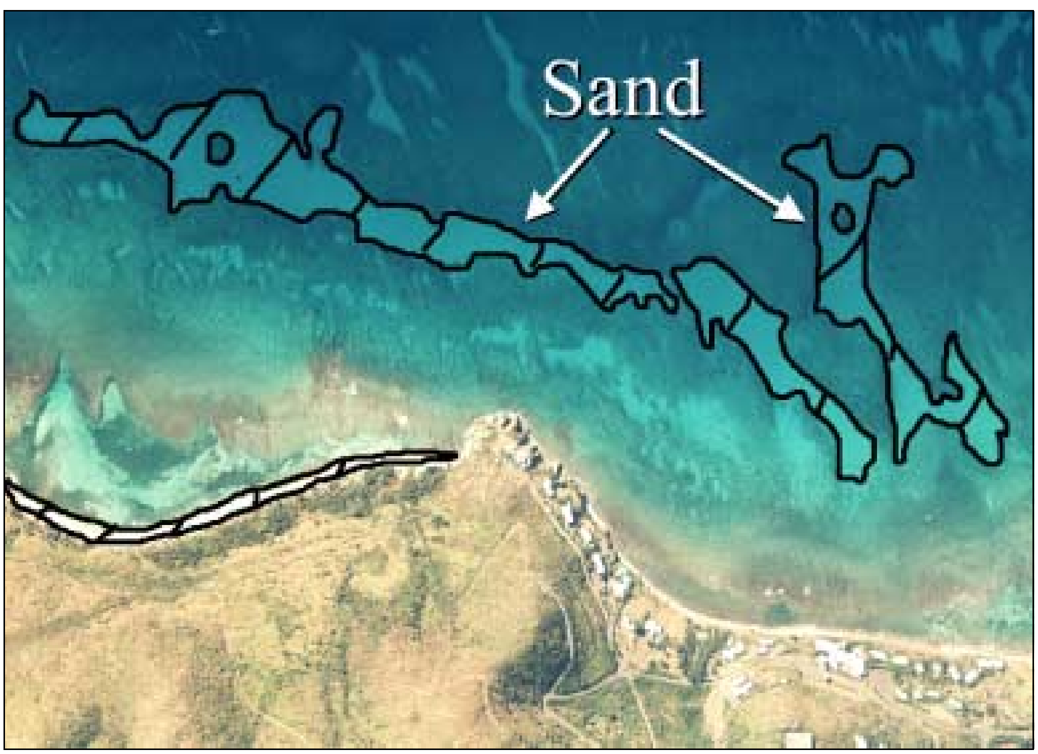
Habitats:

Unconsolidated Sediments: Unconsolidated sediment with <10% cover of submerged vegetation.

Mud: Fine sediment often associated with river discharge and buildup of organic material in areas sheltered from high-energy waves and currents.



Sand: Coarse sediment typically found in areas exposed to currents or wave energy.



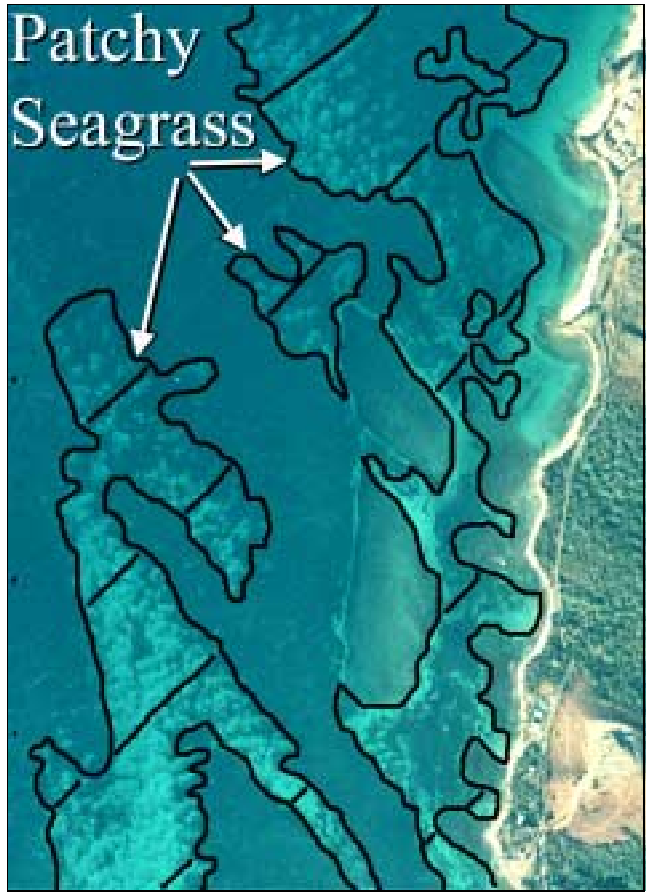
Submerged Vegetation: Greater than 10% cover of submerged vegetation in unspecified substrate type (usually sand, mud, or hardbottom).

Seagrass: Habitat with 10% or more cover of *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila baillonis,* or some combination thereof.

Continuous Seagrass: Seagrass covering 90% or more of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (<MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).

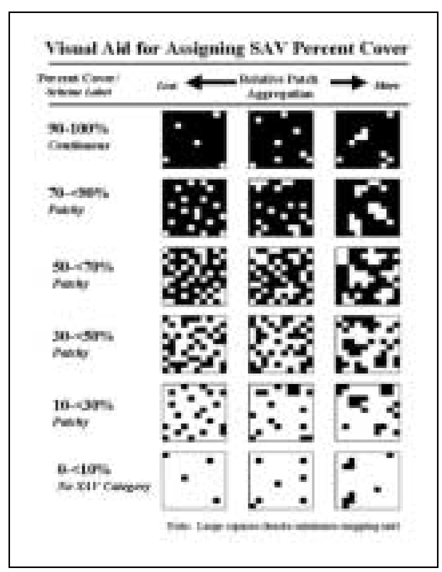
Patchy Seagrass: Discontinuous seagrass with breaks in coverage that are too diffuse or irregular, or result in isolated patches of seagrass that are too small (smaller than the MMU) to be mapped as continuous seagrass.

Representative Species:
Thalassia testudinum
Syringodium filiforme
Halodule wrightii
Halophila baillonis



Visual Aid used for Assigning Degree of Patchiness:

Patchy Seagrass (70%-<90% cover)
Patchy Seagrass (50%-<70% cover)
Patchy Seagrass (30%-<50% cover)
Patchy Seagrass (10%-<30% cover)



Macroalgae: An area with 10% or greater coverage of any combination of numerous species of red, green, or brown macroalgae. Usually occurs in deeper waters on the bank/shelf zone.

Continuous Macroalgae: Macroalgae covering 90% or more of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (<MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).

Patchy Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of macroalgae that are too small (smaller than the minimum mapping unit) to be mapped as continuous macroalgae.

Patchy Macroalgae (50%-<90% cover)
Patchy Macroalgae (10%-<50% cover)

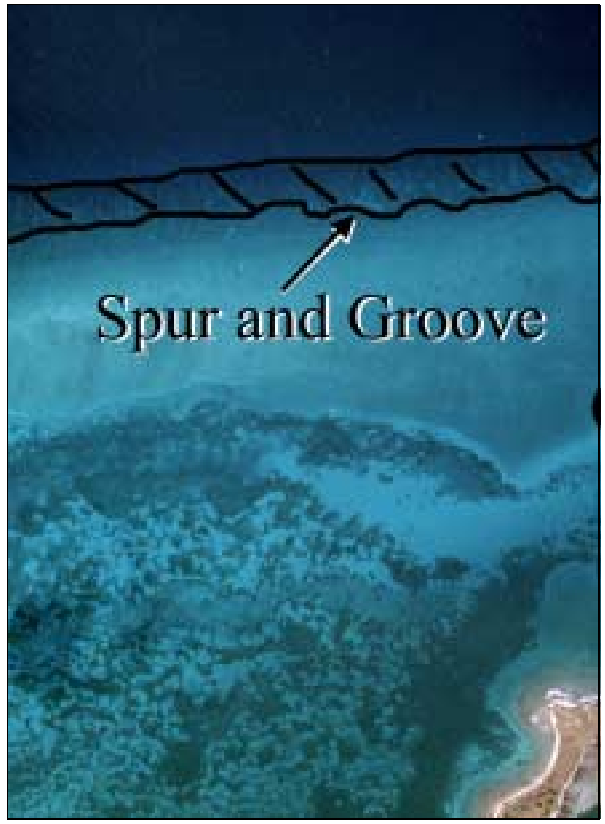
Representative Species:
Caulerpa spp.
Dictyota spp.
Halimeda spp.
Lobophora variegata
Laurencia spp.

Coral Reef and Hardbottom: Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock.

Coral Reef and Colonized Hardbottom: Substrates formed by the deposition of calcium carbonate by reef building corals and other organisms. Habitats within this category have some colonization by live coral, unlike the **Uncolonized Hardbottom** category.

Linear Reef: Linear coral formations that are oriented parallel to shore or the shelf edge. These features follow the contours of the shore/shelf edge. This category is used for such traditional terms as fore reef, fringing reef, and shelf edge reef.

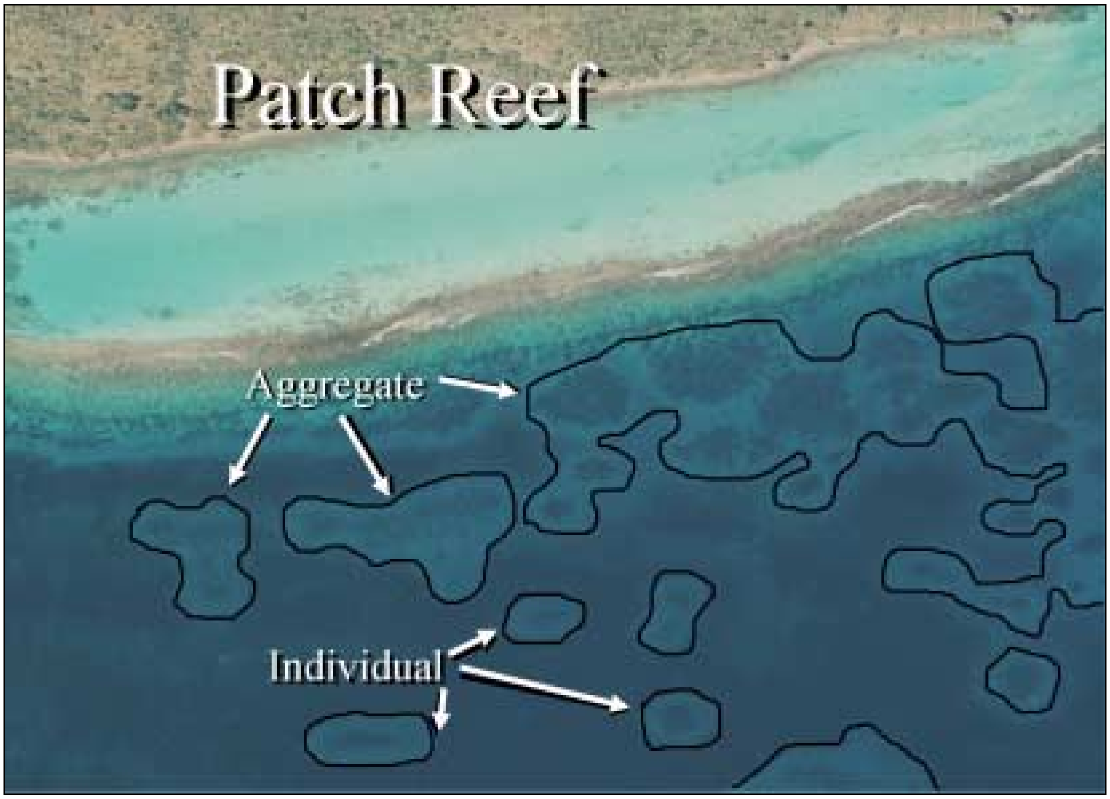
Spur and Groove: Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief (relative to pavement with sand channels, see below) and are separated from each other by 1-5m of sand or bare hardbottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the fore reef or bank/shelf escarpment zone.



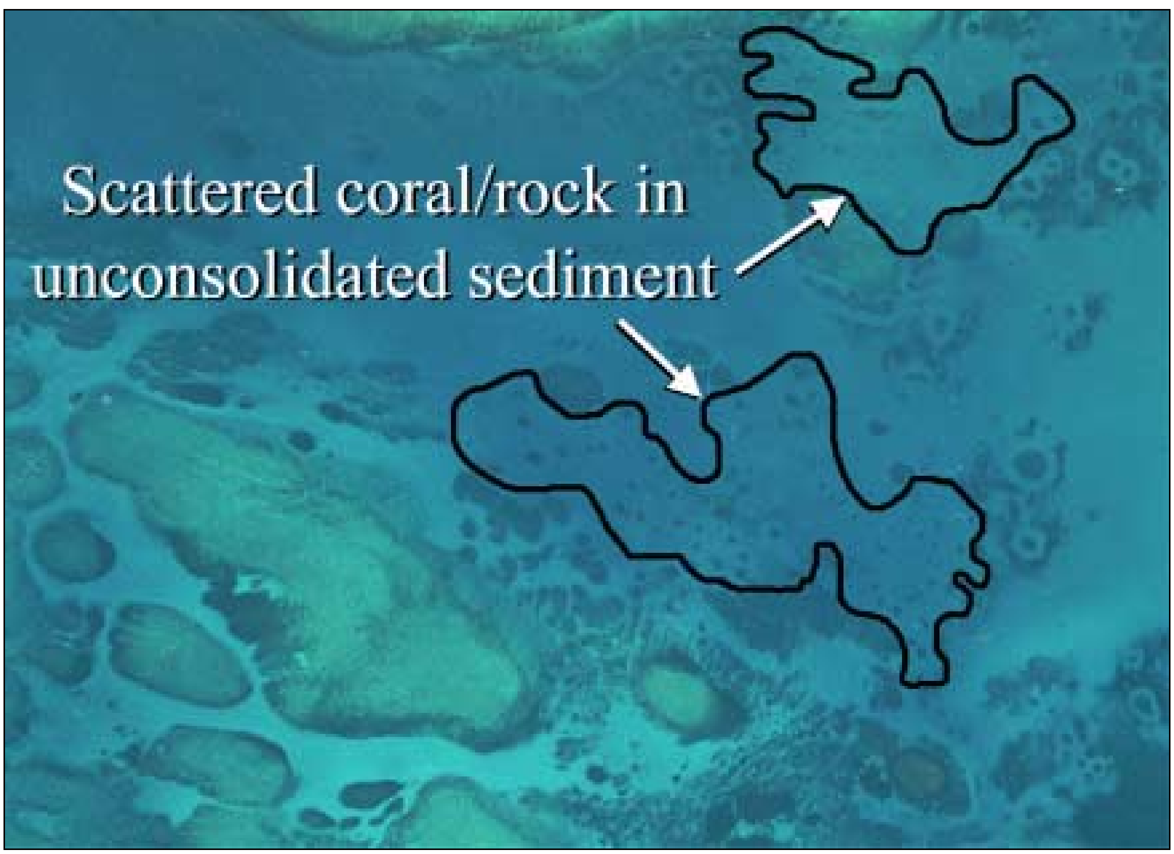
Patch Reef(s): Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. A surrounding halo of sand is often a distinguishing feature of this habitat type when it occurs adjacent to submerged vegetation.

Individual patch reef: Distinctive *single* patch reefs that are larger than or equal to the MMU. When patch reefs occur in submerged vegetation and a halo is present, the halo is included with the patch reef polygon.

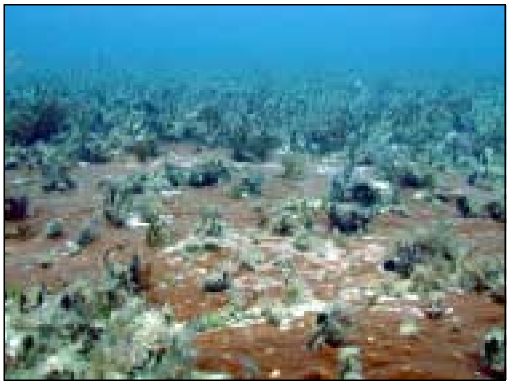
Aggregate patch reefs: *Clustered* patch reefs that individually are too small (smaller than the MMU) or are too close together to map separately. Where aggregate patch reefs share halos, the halo is included in the polygon.



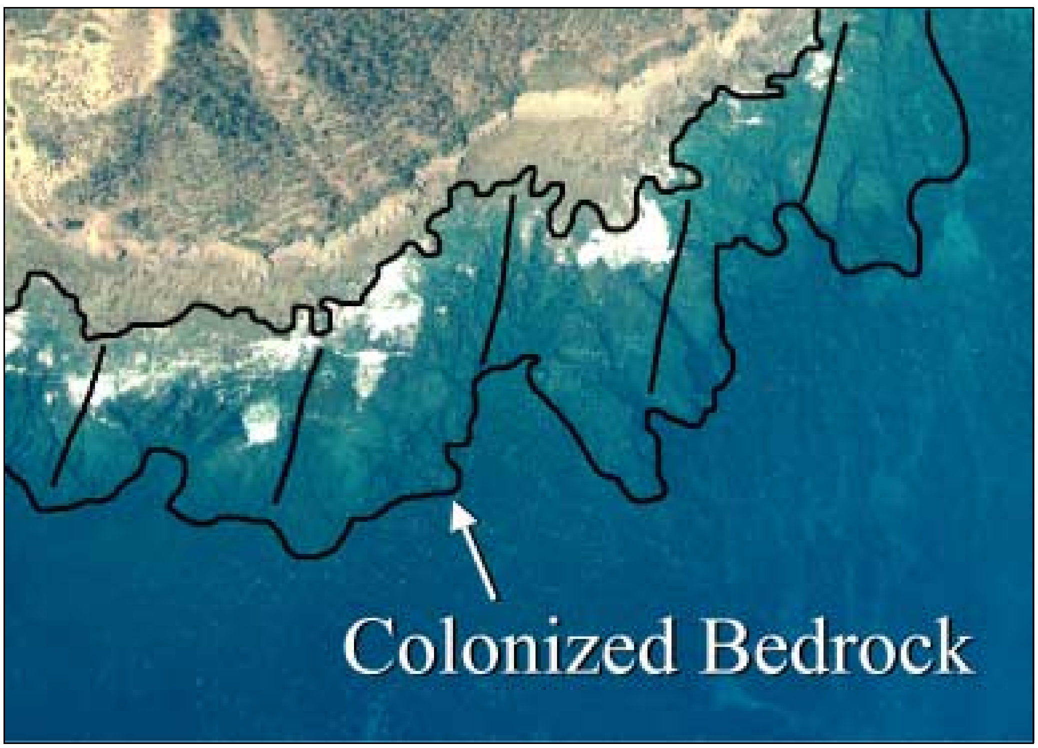
Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e. smaller than "individual patch reef").



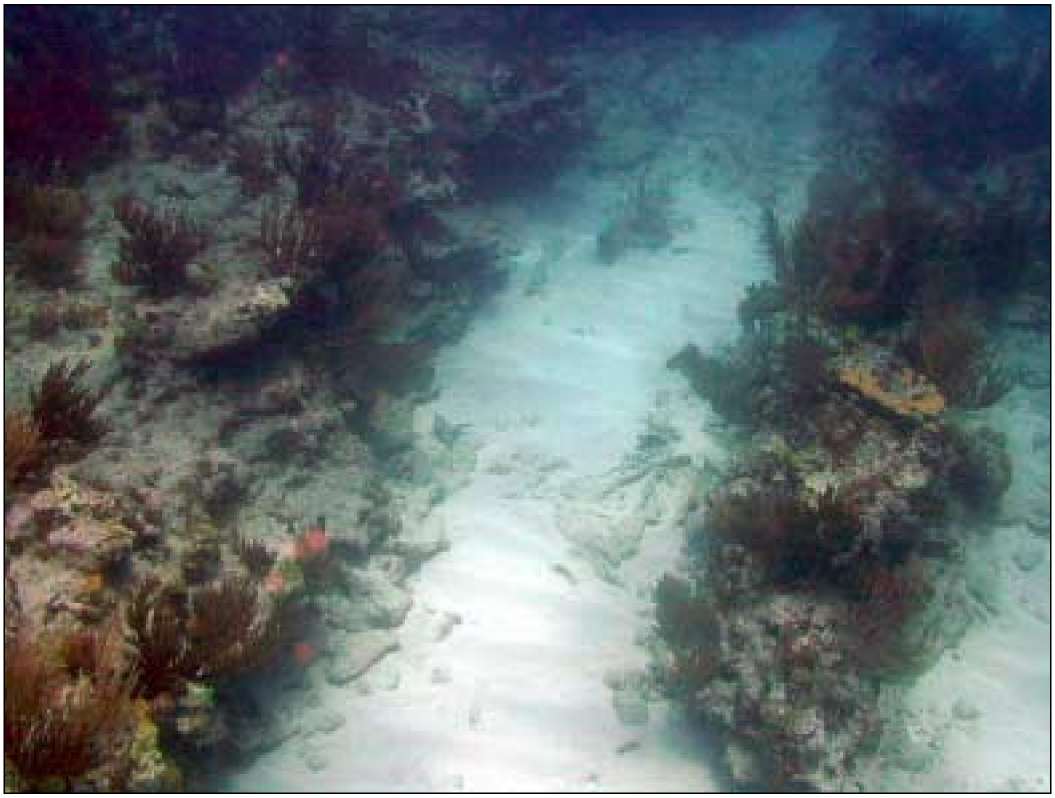
Colonized Pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that are dense enough to begin to obscure the underlying carbonate rock.



Colonized Bedrock: Exposed bedrock contiguous with the shoreline that has coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that begins to obscure the underlying rock.



Colonized Pavement with Sand Channels: Habitat having alternating sand and colonized pavement (see above) formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels of this feature have low vertical relief (relative to Spur and Groove formations). This habitat type occurs in areas exposed to moderate wave surge such as the bank/shelf zone.



Representative Species:
Acropora palmata
Acropora cervicornis
Diploria spp.
Millepora complanata
Montastrea spp.
Porites spp.
Siderastrea spp.

Uncolonized Hardbottom: Hard substrate composed of relict deposits of calcium carbonate or exposed bedrock.

Reef Rubble: Dead, unstable coral rubble often colonized (but not always) with filamentous or other macroalgae. This habitat often occurs landward of well developed reef formations in the reef crest or back reef zone.

Uncolonized Pavement: Flat, low relief, solid carbonate rock that is often covered by a thin sand veneer. The pavement's surface often has *sparse* coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that does not obscure the underlying carbonate rock.

Uncolonized Bedrock: Exposed bedrock contiguous with the shoreline that has s*parse* coverage of macroalgae, hard coral, gorgonians and other sessile invertebrates that does not obscure the underlying rock.

Uncolonized Pavement with Sand Channels: Habitat having alternating sand and uncolonized pavement (see above) formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels of this feature have low vertical relief (relative to Spur and Groove formations). This habitat type occurs in areas exposed to moderate wave surge such as the bank/shelf zone.

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Other Delineations:

Mangrove: Emergent habitat composed of red, black, or white mangroves, or some combination thereof. Mangroves are generally found in areas sheltered from high-energy waves. Mangroves must be part of an open tidal system to be mapped. This habitat type is only found in the shoreline/intertidal, back reef, or barrier reef crest zone.

Representative Species:
Rhizophora mangle
Avicennia germinans
Laguncularia racemosa

Artificial: Man-made habitats such as submerged wrecks, large piers, submerged portions of rip-rap jetties, and the shoreline of islands created from dredge spoil.

Unknown: Bottom type unknown due to turbidity, cloud cover, water depth, or other interference.

Chapter 2: On-Screen Mapping with ArcView's Habitat Digitizer

The Habitat Digitizer Extension to ArcView 3.1 was developed to facilitate mapping the benthic habitats of Puerto Rico and the U.S. Virgin Islands using the classification scheme shown in Chapter 1. The extension was originally created to map habitats using this scheme by visually interpreting orthorectified aerial photos. The extension allows users to rapidly delineate and attribute polygons using simple menus. The extension's capabilities have been expanded to allow users to map from other georeferenced image data such as satellite images and side scan sonar. It also allows new hierarchical classification schemes to be easily created, modified, and saved for use on future mapping projects.

The extension is available for download from the "Benthic Habitats of Puerto Rico and the U.S.Virgin Islands CD-ROM" and also over the internet at http://biogeo.nos.noaa.gov/benthicmap/caribbean. The extension and accessory files are found in the "Habitat_Digitizer.zip" folder. This folder contains three files including:

Habitat.avx	the extension
Coral.hcs	a classification scheme for tropical marine habitats
Coral.avl	an example legend for the coral.hcs classification scheme

Hardware and Software Requirements

The Habitat Digitizer extension is compatible with ArcView 3.1 and requires hardware similar to that recommended for proper operation of ArcView. Additional memory may enhance performance for handling image files, which in most cases are quite large. The appropriate Image Support extension (TIFF, MrSID, etc.) is required depending on the format of the image files used. The Image Analyst extension is not necessary but is also recommended to facilitate manipulation of image brightness, contrast, and color balance.

Getting started

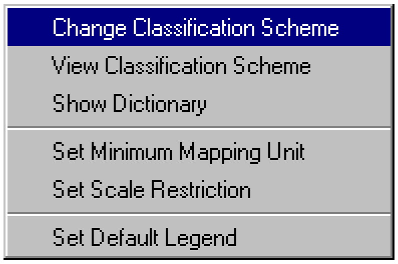
To begin using Habitat Digitizer, save the *habitat.avx* file in either ArcView's Ext32 directory or the USEREXT directory. The *coral.hcs* and *coral.avl* files can be saved anywhere, but preferably, they should be placed in ArcView's default working directory.

After starting ArcView, load the Habitat Digitizer Extension (and any other desired extensions) by selecting "File/Extensions…" and click on the box next to the Habitat Digitizer Extension in the "Available Extensions" list. Click "OK" to install the extension. If a project already exists that used the Habitat Digitizer Extension, opening the project will automatically load the extension.

Setting the Projection Parameters for the Image Data:

The Habitat Digitizer allows users to specify a Minimum Mapping Unit (MMU), digitizing scale, and offers several other spatial functions that require the View's projection and Map Unit's to be set properly. The projection properties of the View must be set to those of the image data from which habitats are being interpreted. Once the View's projection is set properly, shapefiles created using Habitat Digitizer will be unprojected (in decimal degrees). To set the projection properties, select "View/Properties" and set the Map and Distance Units as well as the Projection information of the image. If this information is not set, the shapefile will be created in the projection coordinates of the image files (not in decimal degrees) and the MMU, scale restriction, and other spatial functions of the extension will not work.

The Habitat Digitizer Menu



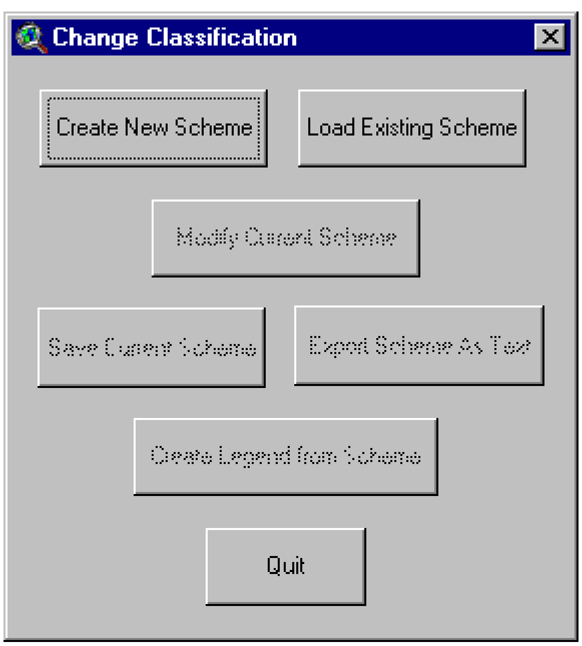
Once the Habitat Digitizer Extension has been activated a “Habitat Digitizer” pull-down menu and digitizing tools which control the functions of the extension will appear on the ArcView toolbar. Beginning with the process of creating and loading classification schemes, a detailed description and instructions for each function in the extension are provided below.

Creating a new classification scheme

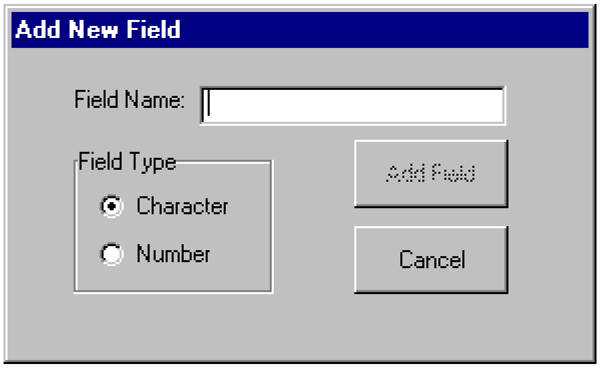
Unless an existing classification scheme such as *coral.hcs* is used, a new scheme must first be created to use the extension. Before creating a new scheme using the dialogs of the extension it may be useful to sketch the scheme out on paper to ensure that all fields and categories in the hierarchy are entered properly. There are several advantages to using a scheme with a hierarchical structure including: the detail of habitat categories can be expanded or collapsed to suit user needs, the thematic accuracy of each category/hierarchical level can be determined, and additional categories can be easily added or deleted at any level of the scheme to suit user needs. An example of a scheme framework is provided in Table 2.1 below to assist with this process.

Table 2.1: Example Classification Scheme Framework

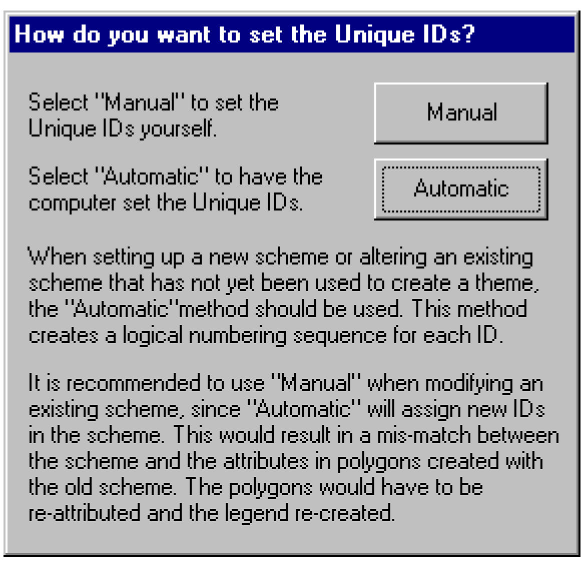
Fieldname 1	*Fieldname 2*	*Fieldname 3*	*Fieldname 4*	*UniqueID*
Category 1	**Subcategory 1**	**Subcategory 1**	**(empty)**	**111**
		Subcategory 2		**112**
	Subcategory 2	**Subcategory 1**		**121**
		Subcategory 2		**122**
Category 2	**Subcategory 1**	**Subcategory 1**		**221**
		Subcategory 2		**222**
	Subcategory 2			**22**
Category 3	**Subcategory 1**			**31**
	Subcategory 2			**32**



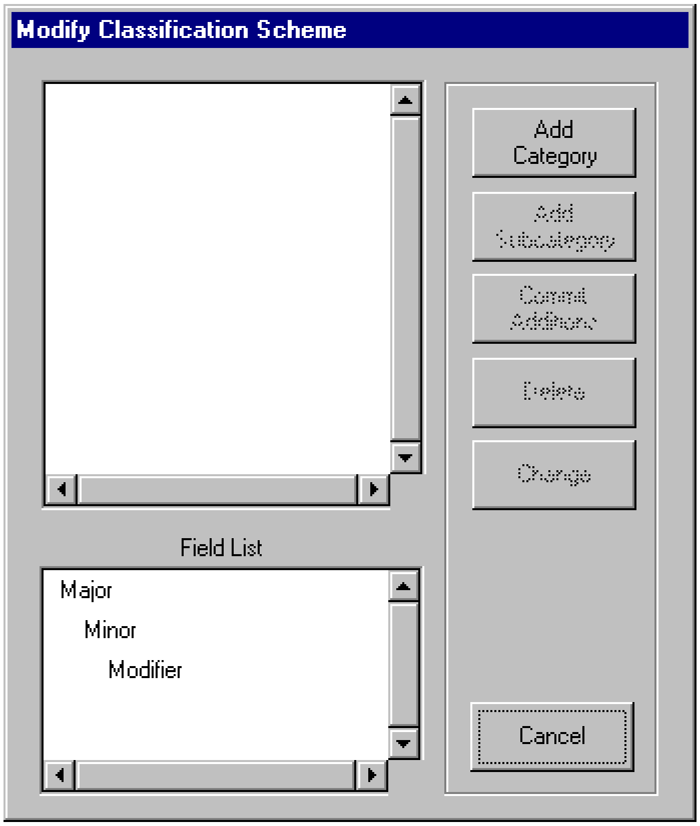
To create the new scheme using the extension, select “Habitat Digitizer/Change Classification Scheme” and in the next dialog box, select “Create New Scheme”. Type in the name of the new classification scheme in the message box and click “Okay”. Until a scheme has been either created or loaded, the other options in this dialog will be unavailable.



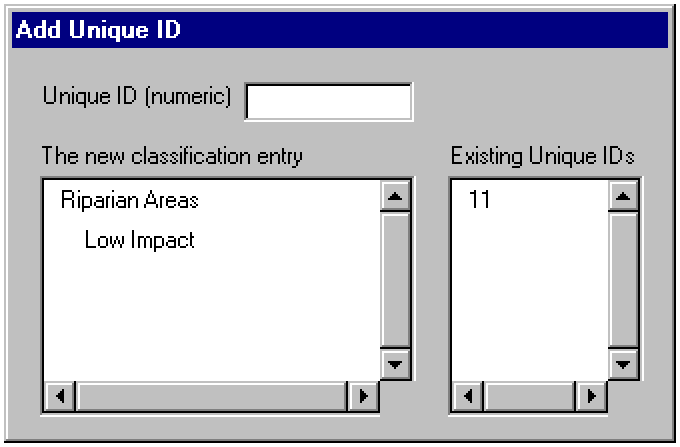
In the "Add New Field" dialog, selecting "Cancel" will end the creation process without creating a scheme. Once the first field name has been added, this button is replaced with the "Finished" button, which will complete the field naming process and go to the next step in creating the scheme. First, type in the field name for the most general hierarchical level in the new classification scheme (Fieldname 1 in Table 2.1). Field names can only be 10 characters long. Select whether the field will be character or numeric and select "Add Field". Add additional field names in the order of the classification hierarchy. A fieldname must be entered for every level in the hierarchy. It may be desirable to add a few extra fields to act as placeholders in case any additional unforeseen levels in the hierarchy are required at a later time. Select "Finished" to proceed to the next step once all the field names have been entered. Once "Finished" is selected, no additional fields may be added to the classification scheme. Also, note that a field named "UniqueID" will be automatically added once "Finished" is selected.



The "UniqueID" field is used by the extension to identify each possible combination of hierarchical categories with one unique number (see Table 2.1). UniqueID's are used by ArcView to generate polygon attributes and assign the legend. The dialog at left sets the method of how the uniqueIDs will be assigned. When setting up a new scheme or altering an existing scheme that has not yet been used to create a theme, the "Automatic" method should be used. The "Automatic" method creates a logical numbering sequence for each uniqueID (see Table 2.1). However, if a scheme that has already been used to create a theme is modified, the "Manual" method should be used. If "Automatic" were used, new uniqueID's would be assigned to the scheme creating a mis-match between the ID's of the new scheme and those of the polygons attributed using the old scheme.

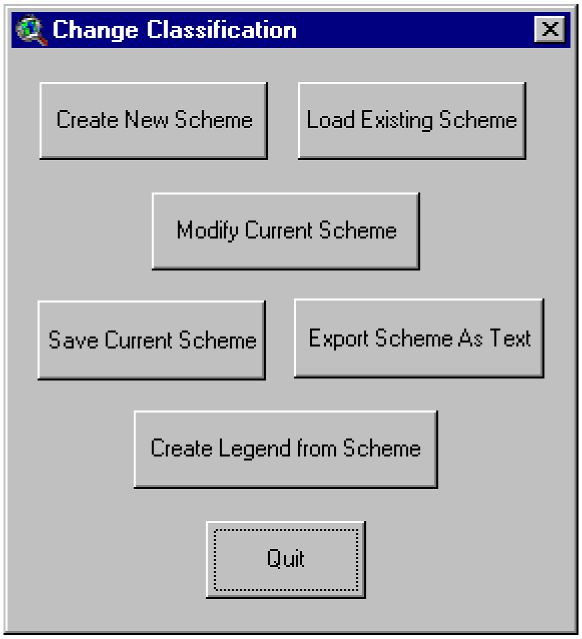


In the "Modify Classification Scheme" dialog, categories and subcategories can be added to a new or existing classification scheme. Begin by adding a category at the most general level in the classification hierarchy (Category 1 in Table 2.1). Click "Add Category", type in the category name and click "Okay". Additional categories at this level in the hierarchy can be added in this way. Adding a category at this level will activate the "Add Subcategory" button. Subcategories are added within individual categories by selecting the category of interest then clicking "Add Subcategory" and completing the dialog boxes. If the uniqueID's are to be assigned using the "Automatic" option (previous dialog), the "Delete" and "Change" buttons are activated and can now be used to adjust category names and locations in the hierarchy using this dialogue. In the "Automatic" method, clicking the "Finished" button will assign a uniqueID to each classification combination. If "Manual" was selected, the "Delete" and "Change" buttons will not be activated until the uniqueID's for each of the categories and subcategories have been added (next dialog). To add unique ID's manually, click the "Commit Additions" button after all categories and subcategories have been added and complete the "Add Unique ID" dialogue box as described below. Once the uniqueID's have been assigned the "Delete" and "Change" buttons will be activated. If the "Cancel" button is selected, the scheme creation process will be ended without creating a scheme.



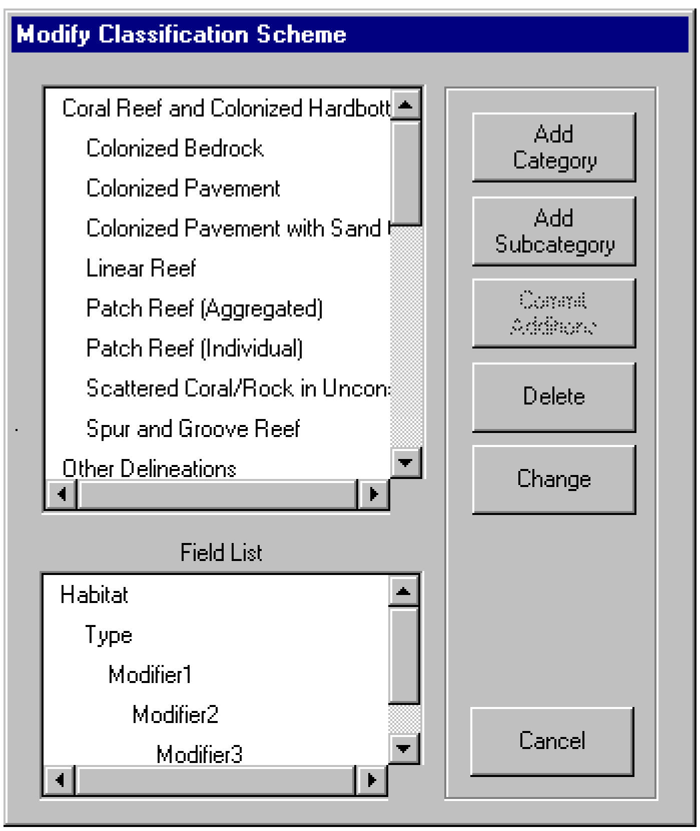
If "Manual" was selected for assigning uniqueID's, the "Add Unique ID" dialog will appear after selecting "Commit Additions". A unique numeric identifier must be entered for each possible combination of classifications in the hierarchy. The "Existing Unique IDs" list shows which numbers are already used in the scheme. Duplicate numbers cannot be added. See Table 2.1 or the *coral.hcs* scheme that is included with the extension to get suggestions on how to assign uniqueID's. Once uniqueID's are set through either the "Manual" or "Automatic" method and "Finished" is selected in the "Modify Classification Scheme" dialog, the new scheme can be saved and used to digitize habitats.

Saving, Re-Loading, and Creating Scheme Legends



Once finished creating or modifying a scheme, save the scheme to a file by selecting “Save Current Scheme” in the “Change Classification” dialog box. The file will be saved as a *.hcs (habitat classification scheme) file. To access this scheme select “Load Existing Scheme” in the “Change Classification” dialog box. A file selection dialog will open showing only the *.hcs files. Additional options that can be used at this time include the “Export Scheme As Text” button which will create a text file showing the hierarchical structure of the scheme, and the “Create Legend from Scheme” button which will create a legend that contains each uniqueID and its attributes. Legend labels will have all of the categories in the classification hierarchy concatenated into one string. Colors will be randomly selected and an additional “Unclassified” category will be added with a uniqueID of 0.

Editing an existing classification scheme

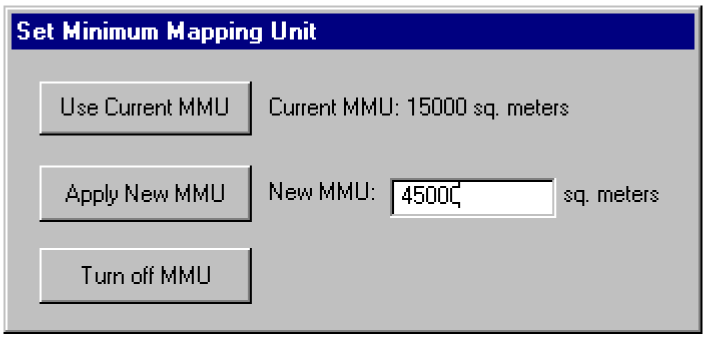


To edit an existing scheme select “Modify Current Scheme” in the “Change Classification” dialog box. After selecting the method of assigning the uniqueID (and in this case, using “Manual” is recommended), the “Modify Classification Scheme” dialog will appear. Follow the same instructions in “Creating a new scheme” to edit this scheme using the dialog at left.

Digitizing Restrictions

Minimum Mapping Unit

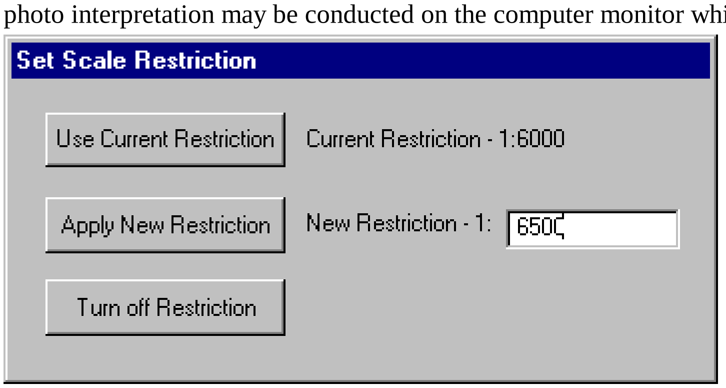
Depending on the quality of aerial images used and the specific goals of the project, it is often desirable to limit the minimum size of the features that are delineated. For example, poor image resolution may preclude the interpretation of features smaller than some minimum size threshold. Other features, while interpretable in the imagery, may simply be too small and therefore beyond the scope or goals of the desired map product. To limit the size of the features that can be digitized in the habitat map, a minimum mapping unit (MMU) can be set in Habitat Digitizer. Features must be larger than the MMU to be included in the habitat map.



Set the MMU restriction by selecting “Habitat Digitizer/Set Minimum Mapping Unit”. If the view’s Map and Distance units are set, a dialog will appear showing the current MMU. Enter the desired numerical MMU into the text box and select “Apply New MMU”. If a satisfactory MMU has already been set, “Use Current MMU” will close the dialog without changing the MMU. Once an MMU is set, if the area of a newly digitized polygon is below the value specified, a message box will ask whether the polygon should be added to the theme. If no MMU restriction is desired, “Habitat Digitizer/Set Minimum Mapping Unit/Turn off MMU” will allow digitizing polygons with no size restriction.

Scale Restriction

It is possible to adjust the scale of the image files as they appear on the computer monitor. For example, the scale of hard copy photographs used for mapping may be 1:48000, however the actual photo interpretation may be conducted on the computer monitor while zoomed in on the scanned photographs at a much larger scale (e.g.1:6000). It is often desirable to conduct all polygon delineation at the same scale, such that all polygons have the same level of detail. Set the scale restriction by selecting “Habitat Digitizer/Set Scale Restriction”. Enter a number in the text box and select “Apply New Restriction”. If digitizing is attemped while a scale restriction is in place and the view is not at the specified scale, a message box will appear and offer to zoom the view to the proper scale. If “No” is selected, a polygon cannot be digitized. If a scale restriction is not desired, use “Habitat Digitizer/Set Scale Restriction/Turn off Restriction” to allow digitizing at any scale.



Creating a theme and using the digitizing tools

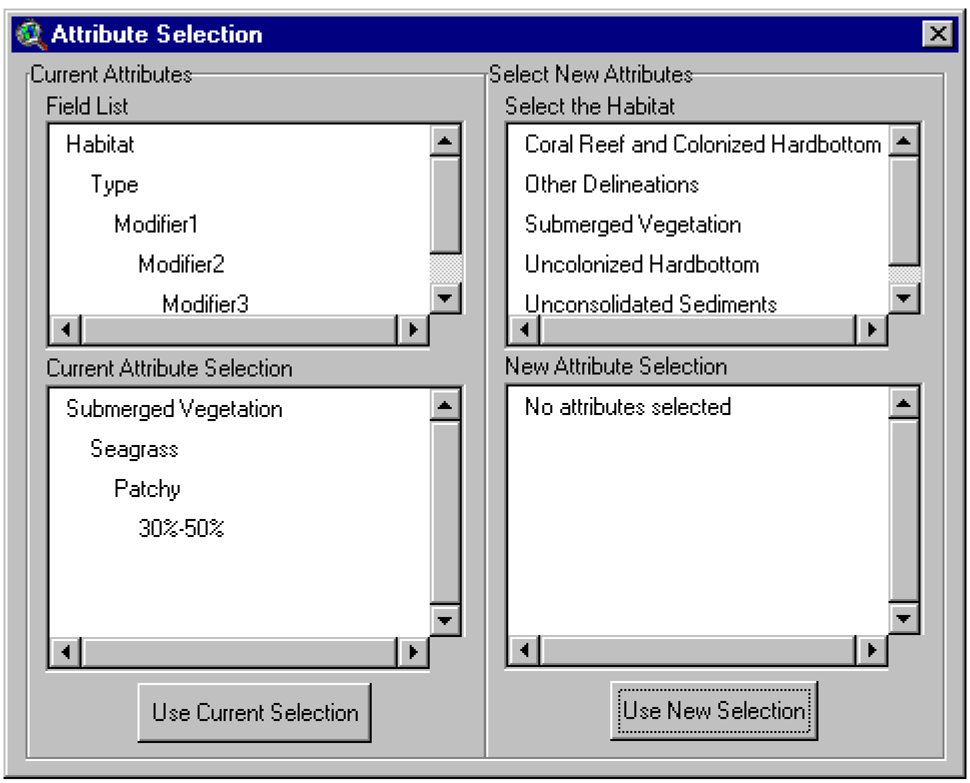
Once a classification scheme has been loaded, this button will create an empty theme with the appropriate fields. If a default legend has not been created using “Habitat Digitizer/Set Default

Legend" or the "Change Classification" dialog, a dialog will appear to select a legend file. A second message box will appear asking if this legend should be made the default legend for all new themes created using this classification scheme.

To start digitizing a new polygon, select this tool and trace the feature of interest by clicking around its perimeter with the mouse. A double click closes each new polygon. If a polygon is digitized inside or completely around an existing polygon, "donut" and "donut hole" polygons will be formed. Once the polygon is complete, a message box will allow the classification to be set as outlined below.

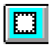
Use this tool to add a polygon adjacent to an existing polygon. To create a polygon using this tool, start tracing a line inside of an existing polygon and end the line by clicking twice inside of the same or another existing polygon. This tool will not work when attempting to digitize a polygon inside of another polygon (use the Split tool below to do that). The scale restriction and MMU also apply to this tool. If several polygons are created with a single line and some are below the MMU, a warning message will appear. If "No" is selected on the warning message only the polygons that fall below the MMU will be removed.

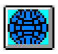
Once polygons are completed using the Add and Append tools a dialog will appear to guide assignment of classification attributes.

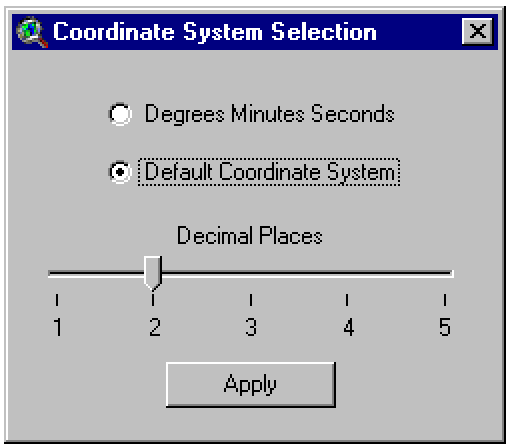


The "Field List" displays the hierarchical structure of the fields in the scheme. "Current Attribute Selection" shows the classification type, if any, currently selected. Either select "Use Current Selection" or select a new classification type by clicking through the desired classification attributes in the "Select New Attributes" window. As new attributes are selected they will be displayed in the "New Attribute Selection" window. The "Use New Selection" button will be activated when the attribute in the lowest hierarchical level for the new classification is selected.

This tool splits one or more polygons into several polygons. All of the attribute information for the resulting polygons will be the same as the original(s) but can be changed as explained below under "Tools from the Right Mouse Button". Please note that due to a bug in ArcView, this tool sporatically works when attempting to split along the inside border of a donut polygon. The scale restriction and MMU also apply to this tool. If several polygons are split and some of the resulting polygons fall below the MMU, choosing "No" will remove the entire line and merge the split polygons back together.

 This button will place a MMU sized red box on the view by clicking the button and then clicking the View at the desired location. This box allows users to estimate the size of features in the imagery relative to the MMU. This box will disappear when panning, zooming in or out, or after completing a polygon. To use this feature while adding a new polygon see "Tools from the Right Mouse Button" below.

 This button brings up a dialog to display the cursor's x/y position in the upper right hand corner of the ArcView window in either the coordinate system of the view (default) showing from 1-5 significant digits, or in degrees, minutes, and seconds. This requires that the view's projection be set and the map units specified.



Tools from the Right Mouse Button

Click and hold down the right mouse button to view a list of additional tools and options:

"Panning" will recenter the display over the spot where the right mouse button was clicked. This is useful while digitizing large polygons that don't fit entirely within the view frame.

"Show attributes" will display a message box showing the habitat attributes for the currently selected polygon.

"Change habitat attribute" will allow the user to change the habitat attributes for existing polygons that are selected.

"**MMU Box**" places an MMU box on the View where the right mouse button was clicked (can be added while digitizing a polygon).

"**Polygon Area**" shows the area of a selected polygon.

Chapter 3: Creating and Interpreting Digital Orthophotographs

Habitat maps of Puerto Rico and the U.S. Virgin Islands were created by visual interpretation of aerial photos using the Habitat Digitizer (Chapter 2). Aerial photographs are valuable tools for natural resource managers and researchers since they provide an excellent record of the location and extent of habitats. However, spatial distortions in aerial photos due to such factors as camera angle, lens characteristics, and relief displacement must be accounted for during analysis otherwise incorrect measurements of area, distance, and other spatial parameters will result. These distortions of scale within an image can be removed through orthorectification. During orthorectification, digital scans of aerial photos are subjected to algorithms that eliminate each source of spatial distortion. The result is a georeferenced digital mosaic of several photographs with uniform scale throughout the mosaic. Once an orthorectified mosaic is created, photointerpreters can accurately and reliably delineate the boundaries of features in the imagery as they appear on the computer monitor using a software interface such as the Habitat Digitizer. Through this process, natural resources managers and researchers are provided with spatially accurate maps of habitats and other features visible in the imagery.

Creating the Digital Mosaic

Aerial photographs were acquired for the Puerto Rico and U.S. Virgin Islands Benthic Mapping Project in 1999 by NOAA Aircraft Operation Centers aircraft and National Geodetic Survey cameras and personnel. Approximately 600, color, 9*9 inch photos were taken at 1:48000 scale of the coastal waters of Puerto Rico and the U.S. Virgin Islands (photography scale varied for some specific islands, see Table 3.1). Specific sun angle and percent cloud cover restrictions were adhered to when possible during photography missions to ensure collection of high quality imagery for the purpose of benthic mapping. In addition, consecutive photos were taken at 60% overlap on individual flightlines and 30% overlap on adjacent flightlines to allow for orthorectification and elimination of sun-glint.

Prints and diapositives (color transparencies) were created from the original negatives. Diapositives were then scanned at a resolution of 500 dots per inch (DPI) using a metric scanner, yielding ~2.4 by ~2.4 meter pixels for the 1:48000 scale photography (pixel size varied for some specific islands due to the scale of the original photography, see Table 3.1). All scans were saved as TIF format for the purposes of orthorectification and photointerpretation. Original TIF's were also converted to *.jpg format to reduce file size and facilitate web serving and are currently available on the NOAA Biogeography Program's web site at 72, 150, and 500 DPI resolution.

Georeferencing/mosaicing of the TIF's was completed in Socet Set Version 4.2.1. First, lens correction parameters were applied to each frame to eliminate image distortion due to the camera lens. Airborne kinematic GPS (location of the aircraft at the time of each exposure) was then used when available to provide a first order geolocation. When this information was not available, measurements were made between flightline strips for input into Socet Set to provide preliminary co-registration.

Image to image tie-points (distinct features visible in overlap areas of each frame such as street intersections, piers, and bridges) were then used to further co-register the imagery, especially for photos taken over open water where ground control points were not available (see below). Socet Set has limited ability to automatically find such features common to overlapping photographs although this automated function performs poorly for submerged features.

Fixed ground features visible in the scanned photos with a known latitude/longitude called ground control points (GCP's) were then used to georeference the imagery (link the pixels to a real world coordinate system such as lat/long). GCP's were collected using real-time DGPS. We obtained points with a wide distribution throughout the imagery, especially on peninsulas and outer islands whenever possible since this results in the most accurate registration throughout each image. Only ground control points for terrestrial features were collected due to the difficulty of obtaining precise positions for submerged features (see Appendix 1: Ground Control Points).

A custom digital terrain model (DTM) was then created using the Socet Set software to correct for feature displacement due to terrain effects. To accomplish this, water features and the shoreline were set to an elevation of zero. Preliminary experimentation revealed that the effects of refraction on the position of submerged features in the imagery were not significant (less than one pixel) enough to make a correction for underwater displacement according to Snell's law. Selected land elevation points were then inserted from USGS 1:24000 Digital Elevation Model's or other elevation data sets where clouds or other sources of interference prevented the Socet Set software from automatically making an accurate DTM. Once the terrain models were complete and a draft orthorectified mosaic was produced, a subset of ground control points was used to measure the quality of each mosaic's rectification and ensure that it met acceptable limits of horizontal spatial accuracy (i.e. RMS value of <1, indicating that, on average, pixels are positioned within one pixel width of their correct location). If the spatial accuracy was not acceptable based on this comparison then additional modifications were made to the DTM, tie-points, etc. until a satisfactory mosaic was created for each island.

Spatial accuracy of the mosaics is reported in Table 3.1. Values reported are an average for the entire mosaic. Therefore, accuracy of features near land (near GCP's) are generally better than the values reported while the accuracy of features away from land is generally not as good (where no land is in the original photographic frame only kinematic GPS and tie points were used to georeference the images). Also, spatial accuracy may be especially poor near clouds over land since this interferes with creation of an accurate DTM.

Once all the photos were orthorectified the best segments of each photo were selected for creation of the final mosaic. Segments of each photo were selected to minimize sun glint, cloud interference, turbidity, etc. in the final mosaic. Where possible, parts of images obscured by sun glint or clouds were replaced with cloud/glint free parts of overlapping images. As a result, most mosaics have few or no clouds or sun glint obscuring bottom features. However, in some cases, clouds, sun glint, or turbid areas could not be replaced with overlapping imagery. In these areas, such obstructions were minimized but could not be eliminated completely.

Segments of 310(?) out of the 600(?) original aerial photos were used to create the final mosaic (Table 3.1). Final mosaics were created in "geoTIF" file format (georeferenced image file) with the following projection parameters: NAD 83, UTM Zone 19 for Puerto Rico, and UTM Zone 20 for the U.S.Virgin Islands. These files are available on the "Benthic Habitats of Puerto Rico and the U.S. Virgin Islands CD-ROM" and at the NOAA Biogeography Program's web site as file type **TBD**. No color balancing was attempted since this alters color and textural signatures in the original imagery and interferes with the photointerpreters ability to delineate habitats. As a result, mosaics have visible seams between adjacent photos. This provided the photointerpreter with "true color" imagery for maximum ability to identify and delineate benthic features.

Table 3.1: Mosaic Specifications for each Island

Location	*UTM Zone*	*Photo Scale*	*Pixel Width (m)*	*# Photos*	*Area (acre's)*	*Avg. Spatial Accuracy*	*Mr.Sid File Size*
St. John	20	1:48000	2.4				
St.Thomas	20	1:48000	2.4				
St.Croix	20	1:48000	2.4				
Culebra	19	1:48000	2.4				
Vieques	19	1:48000	2.4				
Mona	19	1:28000	1.4				
Desecheo	19	1:20000	1.0				
Puerto Rico: South	19	1:48000	2.4				
Puerto Rico: East	19	1:48000	2.4				
Puerto Rico: West	19	1:48000	2.4				
Puerto Rico: North	19	1:48000	2.4				

Digitizing Benthic Habitats

Individual georeferenced mosaics were loaded into ArcView, with the Habitat Digitizer and Image Analysis extensions activated. Each mosaic was then converted into an image analysis file that could be easily manipulated using ArcView's Image Analysis extension (e.g. adjust contrast, brightness, and color). The Minimum Mapping Unit (MMU) restriction was set to 1 acre in the Habitat Digitizer extension. One acre was selected based on the scale of the photography and the objectives of the mapping project. As a result some features visible in the imagery such as small isolated patch reefs and sea walls that, while they are important features, are quite small and are beyond the scope of this mapping project.

Digitizing scale was set to 1:6000 in the Habitat Digitizer. Experimentation indicated that digitizing at this scale optimizes the trade-off between positional accuracy of lines and time spent digitizing. In general, line placement conducted while zoomed in at large scales results in excellent line accuracy and detail but can be quite time consuming, and conversely, while zoomed out, lines can be drawn quickly but lack both detail and positional accuracy.

To determine the optimum digitizing scale to maximize accuracy and minimize map production time, a 25 acre area composed of a variety of habitat types was mapped at 1:1500, 1:3000, 1:6000, and 1:12000 on-screen scale (scale that the image appears on the computer monitor). Five replicates were conducted at each scale. Each trial was timed so we could evaluate the influence of mapping scale on production time. Resulting maps were evaluated for deviations in polygon detail relative to the map digitized at 1:1500 scale. At 1:1500, individual pixels are clearly discernable allowing highly detailed and accurate maps to be created by closely following the contours of even the most convoluted habitat boundary. Additional increases in zoom do not result in an increase in map detail and accuracy since individual pixels are already visible at 1:1500. Therefore, the map created at 1:1500 scale was used as a reference against which to compare maps digitized at 1:3000, 1:6000, and 1:12000 scale.

The results of this experiment indicated that there is no appreciable loss in polygon detail and accuracy by digitizing at 1:6000 while mapping time was dramatically reduced. Therefore all polygons were digitized at this scale except when subtle habitat boundaries were not easily discernable at 1:6000 and zooming out to a smaller scale was required to place boundaries correctly. In this case, digitizing generally took place at a scale of approximately 1:10000.

Using the Habitat Digitizer, habitat boundaries were delineated around signatures (e.g. areas with specific color and texture patterns) in the orthorectified mosaic corresponding to habitat types in the classification scheme (Chapter 1). This was often accomplished by first digitizing a large boundary polygon such as the habitats that compose the shoreline and then appending new polygons to the initial polygon or splitting out smaller polygons within. Each new polygon was attributed with the appropriate habitat designation according to the classification scheme. Brightness, contrast, and occasionally color balance of the mosaic were manipulated with Image Analysis to enhance the interpretability of some subtle features and boundaries. This was particularly helpful in deeper water where differences in color and texture between adjacent features tend to be more subtle and boundaries more difficult to detect. However, particular caution was used when interpretation was performed from altered images since results from color and brightness manipulations can sometimes be misleading.

The original 1:48000 scale color prints and diapositives were available to the photointerpreter to aid in delineating and attributing polygons. The high quality diapostives were frequently viewed under magnification on a light table to aid in this process. Additional collateral information such as previously completed habitat maps, National Ocean Service nautical charts, and other descriptive references dealing with benthic and coastal habitats of Puerto Rico and the U.S. Virgin Islands were also used to assist with image interpretation (Kumpf and Randall, 1961; Rodriguez et al, 1977; Morelock, 1978; Adey, 1979; Goenaga and Cintron, 1979; Beach and Trumbull, 1981; Grove, 1983; Beets et al, 1986; Pilkey et al, 1987; Trias, 1991; Rodriguez et al, 1992; Morelock et al., 1994; Bacle, 1995; Reid and Kruer, 1998; Kruer 1995; Garcia et al. 2000; NOAA et al, 2000).

Ground Validation

Following careful evaluation of the aerial photography and in some cases creation of a “first draft” habitat map through the process outlined above, selected sites were visited in the field including, (1) areas in the aerial photography and mosaic with confusing or difficult to interpret signatures, (2) transects across many representative habitat types occurring in different depths and water conditions, (3) a survey of the

Zones, and (4) confirmation of preliminary habitat delineations if a first draft was produced. Navigating to field sites was accomplished in a variety of ways including uploading position coordinates from the mosaic into a onboard GPS and navigating to those waypoints, onboard PC connected to GPS allowing navigation using digital nautical charts or the mosaic, and visual navigation using landmarks visible in the diapositives. On most occasions, field activities were conducted with the guidance of local experts.

Diapositives and, when available, draft delineations were used in the field to facilitate comparison of signatures in the imagery to actual habitats at each site. Individual sites were visually evaluated by snorkeling and free diving or directly from the boat in shallow, clear water. Habitat transitions were evaluated by swimming transects across habitat types to further guide placement of polygon boundaries. Habitat type(s), zone, approximate depth, position (GPS), image number, and other descriptive information were recorded at each site. Field data for each site was then compiled into a text table with a lat/long field to allow overlay of the field information on the mosaic and habitat polygons (Appendix 2: Ground Truth Points). In addition, where depth and water clarity permitted, the diapositives were used to navigate across multiple bottom features allowing continuous confirmation of habitat types and transitions between each site.

Following processing of the field data, polygon boundaries and habitat classifications were created or revised where necessary and zone attributes were assigned to each polygon using the Habitat Digitizer. This draft of the habitat maps was then reviewed and revised with the guidance of a panel of local experts at peer review sessions in Puerto Rico and the U.S. Virgin Islands and over the internet. Review session participants included members of the local research and management community. During these peer review sessions, particular attention was given to polygons labeled as “unknown” and areas not visited during ground truth activities. Revisions based on comments from local experts were then completed and final habitat maps were produced. Thematic accuracy was assessed for these final maps (see Chapter 4).

Chapter 4: Assessment of Classification Accuracy

Periodic assessment of thematic accuracy during map production is a critical part of any mapping project. Mapmakers want to know how reliably a given habitat type can be classified, called “producers accuracy”; map users want to know what percentage of the polygons labeled with a specific habitat type is classified correctly, called “users accuracy” (Congalton, 1991; Verbyla, 1991). Such periodic assessment is necessary to monitor and maintain acceptable standards of quality following creation of each draft. Most importantly, once final drafts are produced, the reliability of results must be estimated and reported.

Thematic accuracy of the Puerto Rico and U.S. Virgin Islands habitat maps was evaluated for the three most general habitat categories: unconsolidated sediment, submerged vegetation, and coral reef/hard bottom. Accuracy was estimated at each of two locations within the project area that included the full complement of habitat types, depth ranges, and water conditions found elsewhere in Puerto Rico and the U.S. Virgin Islands. For this reason, the accuracy of maps measured at these two locations is assumed to be representative of map accuracy elsewhere in the project area.

In addition, since a novel mapping approach was used to enhance production time and provide additional project deliverables, it was necessary to ensure that maps produced using the ArcView Extension had comparable accuracy to maps produced using more routinely used techniques. To accomplish this goal the thematic accuracy of ArcView maps was compared to the accuracy of maps produced using published and well known photogrammetric techniques.

Goals of the accuracy assessment:

1. Compare the thematic accuracy of maps produced from on-screen digitizing using the ArcView Extension to those produced by digitizing directly from hard copy photos using a stereoplotter.
2. Evaluate the ArcView derived products more thoroughly including areas with different reef environments/ water conditions representative of sites throughout the project extent.

Comparing Thematic Accuracy: On-screen vs. Stereoplotter Digitizing

Buck Island National Monument, St.Croix and the surrounding ecosystem (~5000 acres) was selected as the site for comparing thematic accuracy resulting from on-screen vs. stereoplotter digitizing due to several factors. First, almost all habitat types in the Puerto Rico/ Virgin Islands project area are present at this site (except mud and mangroves). In addition, there is a long history of research focused on the habitat in and around Buck Island resulting in a variety of historical data with which to compare NOAA map products. Finally, there is excellent logistic support for field activities through the National Park Service and USGS.

Maps of this area were created using each of two techniques; the ArcView Extension and on-screen digitizing process described in Chapter 3, and standard photogrammetric techniques using a stereoplotter to visually interpret benthic features from hard copy photos. Maps derived using the stereoplotter were created by the NOAA Coastal Services Center using Coastal Change Analysis Program (C-CAP) protocols. These protocols include widely accepted and commonly used photogrammetric techniques and instruments (see Dobson et al, 1995 for a complete description of this technique). Under these protocols, habitats were delineated directly from stereo pairs of the hard copy aerial photos that were scanned and used to create the orthorectified mosaics described in Chapter 3. Using the stereo plotter, extremely detailed classification of the hard copy imagery is possible. Since the ArcView digitizing technique used to create maps relied on classification from scans of these photos (less resolution relative to the original hard copy), it was important to determine if there is a difference in thematic accuracy between maps produced using the two techniques given the classification categories and MMU described in Chapter 1.

While map production was underway, habitat type at approximately 120 sites was evaluated in the Buck Island test area to compare with habitat delineations derived from each mapping technique. A stratified sampling protocol was used during which sample sites were preselected so that overall thematic accuracy of the three major habitat types across the range of depths and water conditions found in the field could be evaluated. First, a grid with a ~1 acre cell size (MMU) was overlaid on the georeferenced mosaic of the test area. Next, one third of the grid cells were randomly selected as potential sample sites. The number of potential sample sites was further reduced by eliminating grid cells that contained multiple habitat types. This reduced the possibility of using sites that straddle polygon boundaries. Sites near habitat boundaries were avoided since comparing these locations with mapped polygons could be confounded by spatial accuracy of linework and/or coordinates of ground truth points. NOS bathymetry data was then overlaid and used to split the remaining cells into "shallow" or "deep" categories based approximately on the 40-foot isobath to assist with final site selection. This was done to ensure adequate representation of accuracy assessment within two depth strata since depth is a major factor determining the interpretability of benthic features. Site selection was completed by using visual photointerpretation to select 20 sites for each of the three major habitat types within the two depth strata respectively. This process resulted in a total of 120 preselected sites across the range of depths and habitat types found at the test area.

The accuracy assessment dataset was collected in November 1999 for the Buck Island test area; eight months after the aerial photos were obtained. This short time interval minimized the possibility that habitats could have been altered significantly between the time of the aerial photography and collecting the accuracy assessment data.

A datasheet was created based on the categories in the habitat classification scheme to facilitate assessment of habitat type at each site in the field. Each preselected site was navigated to using real time DGPS. Data recorded at each site included habitat type, depth, and other descriptive information. Depth was determined using a hand-held depth sounder. Habitat type(s) were recorded within a ~5-7 m radius around each pre-selected site. Habitat type directly at the DGPS coordinates was recorded first followed by any secondary habitat types observed within the 5-7m radius of the DGPS point. In most cases, habitat type was the same for the DGPS point and area around each site since we preselected grid cells encompassing areas of uniform tone and texture in the imagery. Logistics prevented evaluation of each site on the scale of the MMU (1 acre). Therefore, potential classification errors resulting from the difference between the MMU and size of accuracy assessment sites were accounted for in the analysis. For example, map classification was not considered incorrect in cases where an accuracy assessment point was scored as "sand" in the 5-7 m area and the photointerpreter delineated a large, multiple acre polygon as "patchy seagrass", "aggregated patch reefs", and "colonized pavement with sand channels" since each of these classification categories have large areas composed of sand.

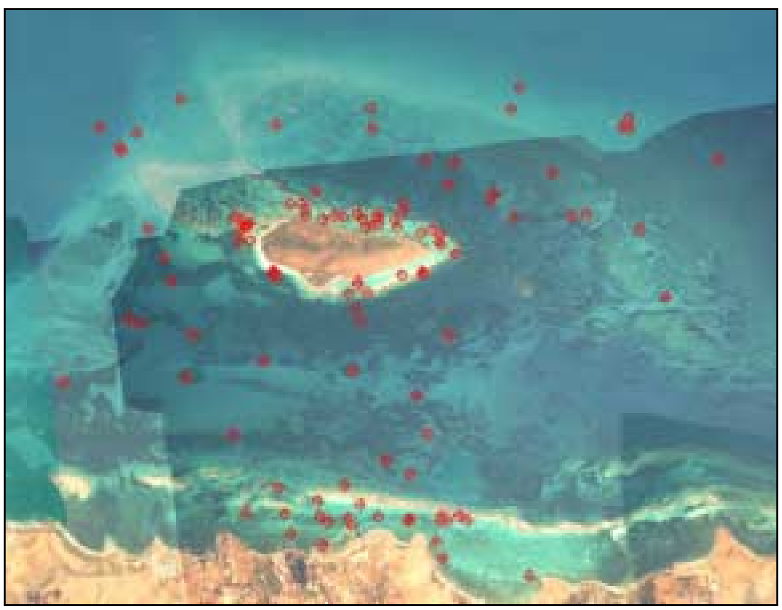


Figure 4.1: Distribution of accuracy assessment points around the Buck Island Reef National Monument test area (n=109).

Logistics prevented reliable data acquisition at 11 of the 120 preselected sites. Therefore 109 sites were used for the accuracy assessment (figure 4.1). Data recorded at each site was overlaid onto the habitat maps and compared against the classification assigned by the photointerpreters. After comparing the map classification to each ground truth site, an error matrix was produced displaying both errors of inclusion and exclusion (tables 4.1-4.2). In addition, overall accuracy, users and producer's accuracy, and Kappa

Statistic (measure of map accuracy relative to a map with classifications randomly assigned expressed as a percent) were reported.

Results: Thematic Accuracy of On-screen vs. Stereoplotter Digitizing

Comparison with the ground truth data revealed very similar levels of thematic accuracy between the two maps. Overall accuracy was 93.6% (Kappa 0.90) for on-screen digitizing and 87.8% (Kappa 0.82) for maps digitized directly from stereo pairs. Maps produced from on-screen digitizing were almost 100% accurate for the submerged vegetation and unconsolidated sediment categories but misclassified a small percentage of hardbottom sites as unconsolidated sediment. Similarly, the maps produced using the stereoplotter were 100% accurate at classifying submerged vegetation but misclassified a small percentage of hardbottom and unconsolidated sediment sites. These findings suggest that both of these mapping techniques result in acceptable levels of thematic accuracy for maps produced at this scale with this type of classification scheme.

Table 4.1: Error matrix for habitat classification using on-screen digitizing at the Buck Island test area. Numbers in the matrix indicate class coincidence, (U) indicates users accuracy, and (P) indicates producers accuracy based on analysis of 109 ground truth points.

Actual Habitat Type

	Coral Reef/ Hardbottom	*Submerged Vegetation*	*Unconsolidated Sediment*
Coral Reef/ Hardbottom	35 97.2% (U) 85.4% (P)	0	1
Submerged Vegetation	0	30 100% (U) 100% (P)	0
Unconsolidated Sediment	6	0	37 86.1% (U) 97.4% (P)

Table 4.2: Error matrix for habitat classification using a stereoplotter at the Buck Island test area. Numbers in the matrix indicate class coincidence, (U) indicates users accuracy, and (P) indicates producers accuracy based on analysis of 98 ground truth points (slightly fewer points were used in this analysis since the extent of this map was smaller than the distribution of ground truth points).

Actual Habitat Type

	Coral Reef/ Hardbottom	*Submerged Vegetation*	*Unconsolidated Sediment*
Coral Reef/ Hardbottom	35 92.1% (U) 89.7% (P)	0	3
Submerged Vegetation	3	25 75.8% (U) 100% (P)	5
Unconsolidated Sediment	1	0	26 96.3% (U) 76.5% (P)

Methods for Evaluation of Thematic Accuracy for other Reef Morphologies and Water Conditions

The results from the Buck Island test area indicated that thematic accuracy of maps produced from on-screen digitizing was good given the clear water and reef morphologies that are representative of that area. However, both geomorphology and local water conditions can dramatically influence the ability to accurately and consistently photointerpret habitats. Therefore, the thematic accuracy of the ArcView derived products were further evaluated in another area with different water conditions and reef morphologies than those present at the Buck Island site and more representative of the environment found elsewhere in the project area. The La Parguera, Puerto Rico area was chosen for additional evaluation of thematic accuracy. The variety of water conditions and habitat types at this site are representative of those occurring elsewhere in the Puerto Rico project area. In addition, there is a long history of research focused on the habitat in and around La Parguera from the University of Puerto Rico, Isla Magueyes Campus resulting in a variety of comparative data with which to compare NOAA map products. Furthermore, there is excellent logistic support for field activities available through the University of Puerto Rico. Sites of accuracy assessment points were selected and analyzed with the same protocol as described above for the Buck Island test area (table 4.3).

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FY 2001 CCMA's BIOGEOGRAPHY PROGRAM STUDIES:
REEF FISH ECOLOGY
Integration of Coral Reef Ecosystem Maps and Species Habitat Utilization Patterns

INTRODUCTION

The Center for Coastal Monitoring and Assessment's (CCMA) Biogeography Team (BT) has initiated several joint projects with the National Park Service, the University of Puerto Rico, and the Puerto Rico DPNR to conduct reef fish ecological studies throughout the US Caribbean Territories in an effort to map benthic habitats, help delineate new Marine Protected Areas (MPA's), and quantify biological communities contained within existing and proposed MPA's in the region, and describe the status and trends of coral reef fish abundance and distribution in US waters. Presently, the research is focussed on Southwestern Puerto Rico, Buck Island Reef National monument (St. Croix), and the Virgin Islands National Park (St. John). Each project, though independently developed, has been designed to provide a standard and consistency of data collection that will enable the BT to assess and compare reef fish abundance and distribution trends throughout the US Caribbean.

Management strategies formulated from findings such as those expected of the BT research and monitoring activities are increasingly accepted as necessary for effective marine resource management (e.g., EFH). This is especially true of the coral reef and associated habitats, where animal movements are closely associated with specific habitats, particularly where these habitats are heterogeneously distributed (Murray *et al.* 1999). Local fishermen have exploited this clear relation between resource and environment with great efficiency in targeting their fishery, resulting in pervasive and dramatic stock declines throughout the region (Appeldorn *et al.* 1992, Beets and Friedlander 1992, Appeldorn 1993). This fact is clearly supported by a significant volume of data suggesting that management strategies within the US Caribbean must be altered in an effort to preserve and nurture what is left of these fisheries (Olsen and LaPlace 1978, Collin 1982, Dennis 1988, Beets and Friedlander 1997).

To that end, the concepts of Marine Reserves (sanctuaries, MPA's, etc.) and Essential Fish Habitat are inextricably linked, and represent an effective and viable management strategy for tropical fisheries. MPA's can benefit fisheries production by (1) protecting vulnerable spawning stock aggregations, (2) enhancing stock abundance in adjacent areas due to the "spill-over" effect (Sluka *et al.* 1997), and (3) by preserving those components of the ecosystem critical to fish growth and survival (Appeldorn *et al*. 2000). Given these benefits, MPA's necessarily represent *de facto* EFH. By maintaining undisturbed habitats, MPA's are likely to provide benefits that far exceed their proportional dimensions. For example, recent field studies in the Exuma Keys Land and Sea Park have estimated that a 20% closure supplies 60% of the egg production of Nassau grouper (Sluka et al., 1997) and 70% of larval queen conch production (Stoner and Ray 1996).

A logical progression of events leading to the definition of a Marine Protected Area would first include an assessment of the function of available habitats relative to managed fishery resources. The resulting demonstration of "essentialness" would then be used as guiding criteria for boundary delineation. In the US Caribbean, there are currently two no-take MPA's: 1) the Luis Peña canal near Culebra Island (Puerto Rico), and the Marine Conservation District (MCD) in Federal waters south of St. Thomas, USVI. Both have only recently been closed. A third location being considered for closure is contained within our proposed study site - the area surrounding Turremote Reef within the La Parguera Natural Reserve along the southwestern shore of Puerto Rico (Appeldorn *et al*. 2000).

To test the efficacy of an MPA's ability to enhance resource abundance, it is critical to develop a baseline against which future biometric estimates can be compared. Crucial to this effort is a sound experimental design that conforms to the questions being asked of the system. At present, there are no comprehensive maps depicting "essential" benthic habitats adjacent to, and contained within, the existing and proposed MPA's. With the completion of the BT’s highly resolved benthic habitat maps of the region (Spring 2001), NCCOS is uniquely poised to quantify meso-scale (<100 km^2) fishery habitat utilization in the area, as well as to suggest cause for the observed patterns by describing species-specific habitat function within the ecosystem. The BT research effort has been designed to provide managers and scientists an evaluation of essential habitat through robust statistical analysis of resource distribution, abundance, and ecological function. In addition the work will provide a benchmark against which future resource surveys can be compared to assess the impact of the MPA’s implementation in the region.

Important updates on project status will be posted on the web as they occur:
http://biogeo.nos.noaa.gov/reef_ecology/

OBJECTIVES

- Define and map benthic habitats within the study area.
- Describe spatio-temporal cross-shelf utilization patterns of benthic habitats by juveniles, sub-adults, and adults of the resident fish assemblages.
- Define species-specific ecological function (e.g., foraging grounds, post-larval settlement, etc.) for the various habitat types which comprise tropical marine ecosystems.
- Develop probabilistic models of fish habitat utilization throughout the entire US Caribbean.
- Quantify biological resources contained within current and proposed MPA boundaries
- Assess impacts of high visitation volumes (tourism) on reef fish communities the Caribbean.

FY 01/02 STUDY APPROACH

Completed benthic habitat maps of the US Virgin Islands will serve as the foundation for developing a monitoring plan. Habitat layers in the map will serve as components to a natural physiographic stratification scheme in which a number of random censuses (minimum of four) will be performed. One station per stratum will be designated as "fixed", while all other censuses in each stratum will differ in location during each monitoring season. In time, this will provide a spatially heterogeneous account of resources in the Park, while satisfying the assumptions necessary for robust statistical analysis and trends analysis.

Basic measures of fish community structure, including species richness (S), species diversity (H'), and abundance (N) will be estimated for each of the sample strata and statistically compared. Results of this excercise can then be linked to the base habitat map, producing a spatial view of the status of fish communities within the Park. High profile species (commercially fished, Federally managed, etc.) will be analyzed independently, and serve as baseline estimates for abundance and distribution for future trends analysis. All censuses will include estimates of fish size (each fish counted) so that ontogenetic shifts in habitat useage can be tracked. A technique termed "reciprocal averageing" will be used to test whether the proportions of each size class among the various habitat types are independent of one another, or whether there is reason to suggest that adult and juvenile fishes (of a given species/family) utilize habitats differently. This suite of analyses will enable managers to track resource status at the community and species level, and provide sound estimates of the biological inventory under their pervue.

FY 01/02 PRIMARY PRODUCTS

1) Several maps shall be produced depicting fish abundance and distribution estimates along the cross-shelf gradient of habitats within the study area. These maps shall be specific to biologically relevant temporal averaging strategies (e.g., climactic season), species, and ontogenetic stage (e.g., adult, juvenile). These maps shall be made available as geographical information systems (GIS) data "layers", and served to all potential users via the WWW. A complete analysis of these data will be performed to identify statistical significance (or lack thereof) in the observed patterns of habitat use. CCMA and CMER personnel shall also distill these data and analyses into a succinct chapter describing the spatial character of the resident ichthyofaunal community.

2) A preliminary report articulating our findings on potential habitat function shall be produced. Included in these reports shall be detailed gut content analyses, as well as all correlative statistics that might be used to infer habitat function.

3) Construction of preliminary models will begin after August 2000. As predictive capacity and reliability are often directly related to sample size, models will be under continuous revision until termination of the project. Final model predictions will be invoked into the GIS benthic habitats data layers. Resulting maps and a detailed analytical description shall be provided through the final project report (FY2003). All data shall be served via the Biogeography Program site (http://biogeo.nos.noaa.gov).

PROJECT CONTACTS

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Differentiating Zones of Community Structure through Exploratory Multivariate Spatial Statistics:

A Potential use of Canonical Correlation in Landscape Models to Define Ecologically Relevant Boundaries

Canonical correlation is a generalization of correlation and regression that is applicable when the attributes of a single group of objects can be divided naturally into two sets (e.g., parameters of fish community structure at sampled sites and physiographic characteristics at the same set of sites). Canonical correlation calculates the overall correlation between the two sets. Linear combinations within the first set of variables (L1), and within the second set (L2), are considered simultaneously, and the linear combinations that maximize the correlation between L1 and L2 are selected.

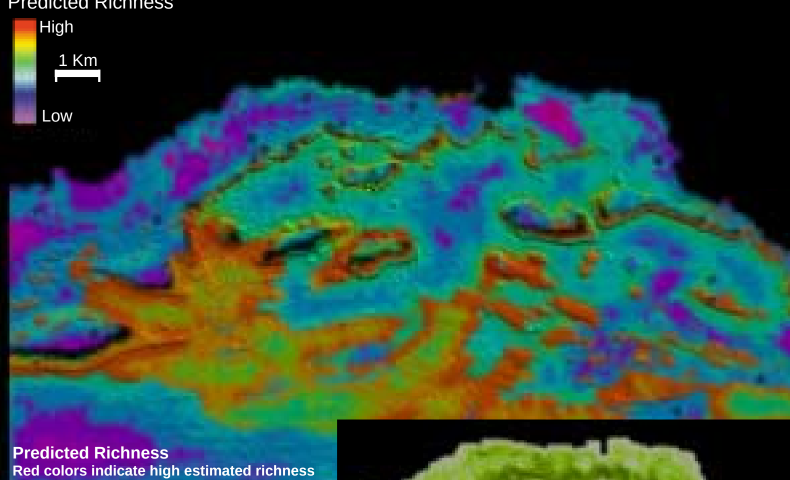
In this exploratory analysis, we used field-based parameter estimates of reef fish community structure (S, H', N) from a variety of habitats along a cross-shelf gradient in Southwestern Puerto Rico, along with estimates of the physical environment (bathymetry, habitat type) at each site. What makes this analysis unique, is that from the spatial distributions of these environmental characteristics, we were able to calculate physiographic variability within the landscape through neighborhood analyses. This technique allows us to estimate habitat and bathymetric variation within prescribed distances away from the source (sample), thereby synthesizing new data to use in the canonical correlation procedure.

This preliminary analysis indicates that species richness shows a strong correlation to canonical root 1 (vector 1 - see regression below), which includes bathymetry, and various combinations of bathymetric*habitat variation. The chi-square test below indicates that the cononical model correctly predicted locations within the entire landscape to be above (high) or below (low) the median richness value 80% of the time. The model was developed using data collected in August of 2000, and validated with richness values estimated from our June 2000 field mission. This analysis is only a conceptual model, and is currently under further development.

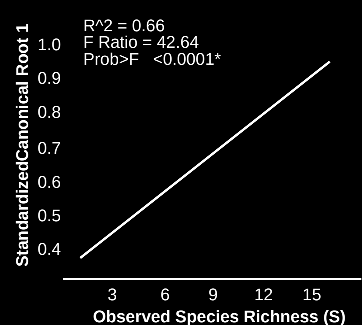
observed

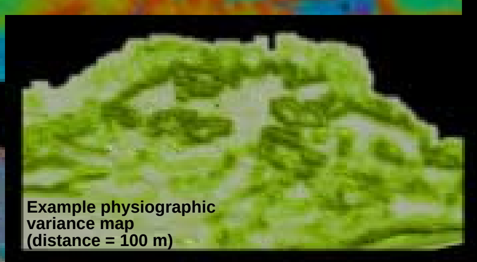
predicted	Count Total % Row % Col %	*Low Richness <Median*	*High Richness >Median*	Σ
	Low Richness <Median	10 41.67 83.33 76.92	2 8.33 16.67 18.18	12 50.00
	High Richness >Median	3 12.50 25.00 23.08	9 37.50 75.00 81.82	12 50.00
		13 54.17	11 45.83	24

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	8.795	0.0030**
Pearson	8.224	0.0041**

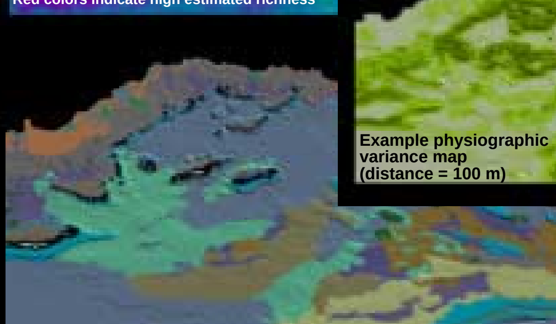


Predicted Richness
Red colors indicate high estimated richness

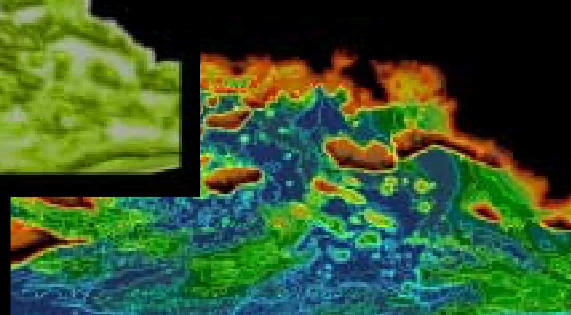




Example physiographic variance map (distance = 100 m)



Benthic Habitats: *calculate habitat variance at multiple scales*



Bathymetry: *calculate bathymetric variance at multiple scales*

MAIN EIGHT HAWAIIAN ISLANDS MAPPING PRODUCTS

Available Now:

1. Draft classified maps of coral reefs along the northwestern Kona Coast, Hawaii and Kaneohe Bay, Oahu. These maps depict as many as 37 categories of habitats and are based on interpretation of hyperspectral imagery.

2. A report summarizing the results of an accuracy assessment of visual interpretation of hyperspectral imagery for shallow-water coral reef mapping at selected sites in the eight main Hawaiian Islands.

3. A georeferenced, orthorectified mosaic (circa 1990) of Hawaiian Islands from Landsat 4/5 multispectral satellite imagery.

4. A georeferenced, orthorectified mosaic (circa 2000) of Hawaiian Islands from Landsat 7 multispectral satellite imagery.

5. A peer-reviewed Coral Reef Ecosystem Habitat Classification scheme, which is required for consistent mapping and characterization of the habitats.

6. Approximately 550 1:24,000 scale color aerial photographs covering approximately 500 kilometers (1/3) of the shoreline of the eight main Hawaiian Islands. These images are available as 500 dpi TIFF files on CD-ROM.

7. Hyperspectral imagery covering approximately 500 kilometers (1/3) of the shoreline of the eight main Hawaiian Islands.

9. A digital data set of over 500 site characterizations of benthic habitats for portions of the eight main Hawaiian Islands.

10. An ArcView GIS-based Habitat Digitizer Extension available for use on any PC operating ESRI ArcView software.

11. Several multi-year contracts with Hawaii private companies and a cooperative agreement with the University of Hawaii to continue to develop mapping products.

Soon-to-be-Available (within 6 months):

1. Draft classified maps of coral reefs along the Kihei Coast, Maui. This map depicts as many as 30 categories of habitats and is based on interpretation of hyperspectral imagery.

2. A report summarizing the results of an accuracy assessment of computer interpretation of high-resolution satellite and hyperspectral imagery for shallow-water coral reef mapping at selected sites in the eight main Hawaiian Islands.

3. Draft classified maps of coral reefs of Oahu, Maui, and the Kona Coast of Hawaii. These maps will depict as many as 30 categories of habitats and are based on interpretation of digital imagery.

4. An integrated network of GPS- and tide-controlled monuments for the eight main Hawaiian Islands.

5. An established datum and geoid for the eight main Hawaiian Islands.

6. Available on the Web - a downloadable georeferenced, orthorectified mosaic (circa 1990) of eight main Hawaiian Islands from Landsat 4/5 satellite imagery.

7. Available on the Web - a downloadable georeferenced, orthorectified mosaic (circa 2000) of eight main Hawaiian Islands from Landsat 7 satellite imagery.

8. Available on the web - rectified JPEGs of approximately 550 1:24,000 scale color aerial photographs covering approximately 500 kilometers (1/3) of the shoreline of the eight main Hawaiian Islands.

9. Available on the web - A PDF file of a revised and updated version of the Hawaiian Islands Coral Reef Classification Scheme, which will include sections on both the eight main Hawaiian Islands and the Northwestern Hawaiian Islands.

10. Classified Landsat satellite-based maps of land areas of the eight main Hawaiian Islands.

11. High-resolution shallow-water bathymetric data for most of Oahu, Molokai, and portions of Hawaii (Navy, USGS, USCOE, and NOAA)

12. A series of georeferenced AVIRIS moderate resolution hyperspectral imagery for portions of the eight main Hawaiian Islands (NASA and NOAA).

Soon-to-be-Available (within 18 months):

1. Additional digital imagery of the shoreline of the Hawaiian Islands. These images will be georeferenced and made available over the Web.

2. Draft classified maps of coral reefs of Molokai, Kauai, and the remainder of Hawaii. These maps will depict as many as 30 categories of habitats and are based on interpretation of digital imagery.

Northwestern Hawaiian Islands Mapping Products

Available Now:

1. Draft classified maps of the coral reefs of Kure Atoll and Pearl and Hermes Atoll. These maps depict as many as 8 categories of habitats and are based on computer-aided analysis of high resolution satellite imagery.

2. Approximately 250 water-based point location descriptions for many of the NWHI areas. These descriptions play an important role in mapping and characterizing the reefs of the NWHI.

3. A draft Coral Reef Ecosystem Habitat Classification scheme for the NWHI, which is required for consistent mapping and characterization of the habitats.

4. Hydrographic survey bathymetry data for Kure Atoll, Midway Islands , and Pearl and Hermes Atoll. These data are important for mapping and characterizing the reefs in these areas.

<u>Soon-to-be-Available (within 6 months):</u>

1. Draft classified maps of coral reefs of Lisianski and French Frigate Shoals. Maps depict up to 8 habitat categories and are based on computer analysis of high resolution satellite imagery.

2. Approximately 400 water-based point location descriptions for Kure Atoll, Midway Islands, Pearl and Hermes Atoll, and, possibly, Lisianski. These descriptions play an important role in mapping and characterizing the reefs of the NWHI.

3. A georeferenced, orthorectified mosaic of Northwestern Hawaiian Islands from Landsat 5 and Landsat 7 satellite imagery.

4. A network of GPS- and tide-controlled monuments for most Northwestern Hawaiian Islands.

5. An established datum and geoid for the Northwestern Hawaiian Islands.

6. A classified map of the shallow-water areas of the Northwestern Hawaiian Islands. This map will depict up to 8 habitat categories and is based on computer analysis of satellite imagery.

7. Several multi-year contracts with private companies and a cooperative agreement with the University of Hawaii to continue to develop Northwestern Hawaiian Island mapping products.

8. A report summarizing the results of an accuracy assessment of computer interpretation of high-resolution satellite imagery for shallow-water coral reef mapping at selected sites in the Northwestern Hawaiian Islands.

9. A series of georeferenced AVIRIS moderate resolution hyperspectral imagery for portions of the Northwestern Hawaiian Islands (NASA and NOAA).

<u>Soon-to-be-Available (within 18 months):</u>

- A complete series of draft Northwestern Hawaiian Island coral reef maps based on high-resolution satellite imagery.

BENTHIC HABITATS OF THE MAIN 8 HAWAIIAN ISLANDS: MAPPING MARINE RESOURCES TO SUPPORT COASTAL ZONE MANAGEMENT, RESEARCH, AND FISHERIES MANAGEMENT.

INTRODUCTION

NOAA's National Ocean Service in partnership with Hawaii-based academic institutions, the Department of Lands and Natural Resources, and the private sector is leading an investigation to consistently and comprehensively map the distribution of coral reefs and other benthic (bottom) habitats throughout the main 8 Hawaiian Islands. This work supports the US Coral Reef Task Force and their directive to develop digital coral reef maps for all US waters. The Mapping and Information Synthesis Work Group of the Task Force has identified the main eight Hawaiian Islands (MHI) as high priority area to develop digital benthic habitat maps. However, all US islands, territories, commonwealths, and freely associated states are components of the Work Group's Mapping Implementation Plan (see http://biogeo.nos.noaa.gov/MIP).

Data collection for the main 8 islands was initiated in year 2000 and 550 1:24,000 color aerial photographs were obtained and converted to digital imagery. In addition, hyperspectral imagery (a camera which captures many wavelengths of light) was collected for about 1/3 of the near-coast coral reefs. A major goal of the Hawaii mapping program is to develop a standard set of protocols for benthic habitat mapping using a suite of technologies ranging from satellite, aircraft, and in-situ sampling platforms. Emphasis will be placed on airborne high resolution remote sensing tools to enable development of comprehensive benthic habitat maps for all US coral reef ecosystems within 5-7 years (MIP, 1999).

The aerial photographs and experimental hyperspectral images are being used to create digital maps of the marine resources in the region including coral reefs, seagrass beds, algal beds, and other important areas for fisheries, tourism, and other aspects of the coastal economy. The primary product of this effort will be benthic habitat maps contained within a Geographic Information System (GIS). In addition, the experimental hyperspectral imagery is one of the most comprehensive data sets collected with this technology to determine its ability to support benthic habitat mapping. The specific methods used to produce the habitat maps will be documented in a methods manual and provided to the local research and management community's to build their ability to conduct similar habitat assessments in the future. Digital photographs, the classification manual, and GIS coverages of the benthic habitat maps, and the hyperspectral database will be disseminated via electronic media.

Important updates on project status will be posted on the web as they occur:
http://biogeo.nos.noaa.gov/benthicmap/pacific/.

OBJECTIVES

1) Collect data required to delineate coral reef ecosystem habitats (N=37) and develop georeferenced digital habitat maps for the main 8 Hawaiian Islands.
2) Provide digital photographs and interpreted photo-mosaics and imagery to the research and management community.
3) Create a habitat classification manual that outlines the specific methods used to create the habitat maps.
4) Determine the feasibility of using regional hyperspectral databases in the development of benthic habitat maps.

FY 01/02 STUDY APPROACH

Digital photographs and complementary hyperspectral data will be obtained for the remaining 2/3 of the main 8 Hawaiian over a 12 month period beginning in the fall of 2001. Data collection in 2001 will mimic collection efforts for year 2000 with the area from the shoreline to water depths of approximately 30 meters (the approximate limit of feature detection for digital photographs and hyperspectral data) studied. Visual interpretation using NOS derived software enables "heads-up" identification and delineation of 37 different habitat types found throughout Hawaii coral reef ecosystems. In addition, the complementary hyperspectral data set is under analysis with the University of Hawaii to determine if computer generated habitat maps can be derived from the unique "spectral signatures" (reflectance of light) of benthic habitats. This developing tool provides great promise to map coral reef ecosystems much more rapidly and using objective classification rules.

FY 01/02 PRIMARY PRODUCTS

1) Digital Aerial Photographs
2) Hyperspectral Imagery and results of mapping experiments.
3) Draft GIS maps (Electronic and hard copy) showing the distribution of benthic habitats in several test areas (including Kanehoe Bay, Ohau and Kona coastline, Hawaii)
4) Habitat Classification Manual
5) Digital maps of types of land cover integrated with benthic habitat maps for one island.

PROJECT CONTACTS

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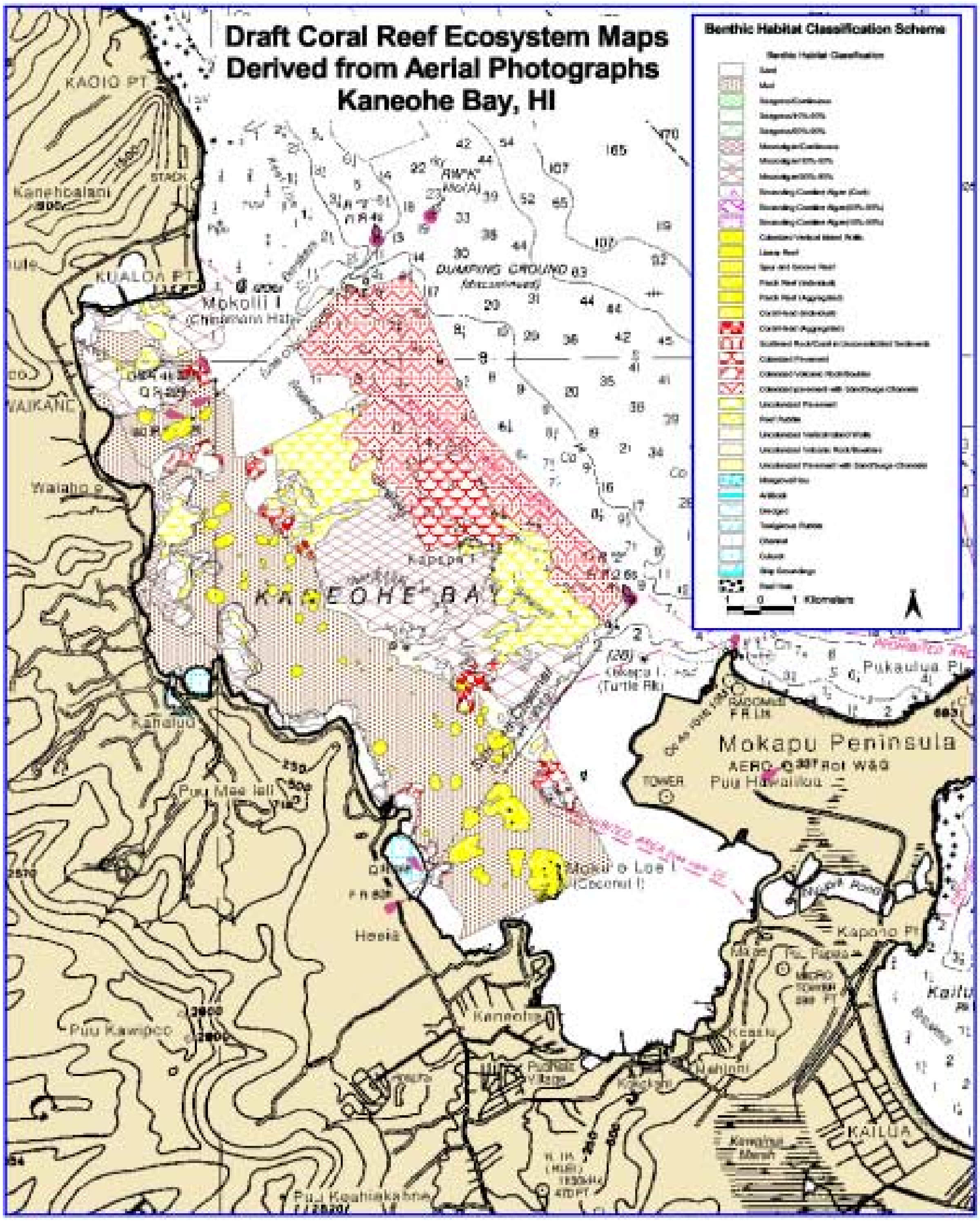


Fourth DRAFT

HAWAII BENTHIC HABITAT CLASSIFICATION SCHEME

FOR MAPPING OF MAIN 8 HAWAIIAN ISLANDS:

August 15, 2000

PREPARED BY

NOAA'S NATIONAL OCEAN SERVICE
NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE
CENTER FOR COASTAL MONITORING AND ASSESSMENT
BIOGEOGRPAHY & REMOTE SENSING PROGRAMS

IN COOPERATION WITH FEDERAL, STATE, ACADEMIC, & PRIVATE SECTOR PARTNERS FOR THE DEVELOPMENT OF HAWAII DIGITAL BENTHIC HABITATS MAPS IN RESPONSE TO THE
US CORAL REEF TASK FORCE NATIONAL ACTION PLAN

Background:

NOAA's National Ocean Service (NOS) is attempting to acquire comprehensive aerial photographs for the nearshore waters of the main 8 Hawaiian Islands. In addition, a hyperspectal experiment will be conducted in Kanehoe Bay on O'hau and complement efforts to obtain hyperspectal imagery for portions of the main 8 islands. The imagery will encompass the area from the shoreline out to about 20 meters in water depth. The images will be used to create digital maps of Hawaii's marine benthic habitats including coral reefs, algal flats, seagrass beds, mangrove forests, and other important habitats for fisheries, tourism, and other aspects of the coastal economy. An initial step in producing benthic habitat maps is the development of a habitat classification scheme. The purpose of this document is to continue the process to develop the benthic habitat classification scheme for the aerial photography and hyperspectral imagery for the main 8 Hawaiian islands. **Complementary schemes will be required for the Northwest Island Hawaiian Islands and other US areas in the Pacific (e.g. Guam).**

The applied mapping component of this project is the use of digital aerial photography as the source data to develop benthic habitat maps from visual interpretation using "heads up" (on screen) computer digitizing. If all of the 92 flight lines are eventually flown (63 lines have be flown in 2000), about 1,700 photographs will need to be scanned, georeferenced, mosaiced, and interpreted based upon expert visual interpretation. In some instances, automated multispectral image analysis (e.g. R-G-B classification) may be used to obtain a crude level of classified map product (e.g. hardbottom, sand, and algae). Regardless of the technique used to interpret the photographs, it is a very time consuming to develop digital photographs into georectified mosaics that are suitable for visual interpretation. Thus, a very important complementary component of the mapping of the Hawaiian Islands is the collection of imagery using a hyperspectral scanner. The hyperspectral imagery is digital and can be georeferenced "on the fly". The first objective of the hyperspectral experiment is to show that for a large region a hyperspectral scanner can be used to produce digital georeferenced imagery that has equal, or greater feature detection quality, when compared to aerial photography. The hyperspectral imagery must be of sufficient quality to enable visual interpretation of the imagery into classified habitat maps. A second objective of the hyperspectral component, is to demonstrate that computer algorithms can automatically classify the digital imagery based upon the spectral characteristics of specific habitats (e.g. coral, sand, algae).

Regardless of whether aerial photographs or hyperspectal imagery are used to map the Hawaiian Islands, either set of imagery will need to be classified into levels of classification that meet the needs of both the management and scientific community. The fourth draft of the classification scheme is an important step in determining the type of map products to be produced from the aerial imagery. To facilitate development of the digital benthic habitat maps, NOAA and its partners will produce a Classification Manual that will document the specific methods used in image interpretation and habitat classification. Components of the Classification Manual will include: list of the classified habitats, description of the habitats, and a decision system for assigning habitat classifications using either aerial photography or hyperspectral imagery. In addition, portions of the hierarchical classification scheme can be used to classify satellite imagery. This is an important aspect of the scheme as it will enable a "common language" compare and contrast digital maps developed from complementary remote sensing platforms.

Developing the Classification Scheme:

A hierarchical classification scheme will be used to define and delineate habitats. The draft classification scheme was influenced by many factors including: requests of the management community, NOS's coral reef mapping experiences, existing classification schemes for the Pacific and Hawaiian Islands and other coral reef ecosystems, quantitative habitat data for the Hawaiian Islands, the minimum mapping unit (MMU, 1 acre for visual photointerpretation, to be determined for hyperspectal image interpretation), and anticipated limitations of the data. **Most important, if a feature (e.g., habitat) cannot be detected or seen in the photographs or hyperspectral imagery or classified by its spectral signature, it is not included in the scheme.**

The classification scheme is hierarchical to allow users to expand or collapse the detail of the resulting map to suit their needs, but also to allow image interpreters to classify benthic communities to the most accurate resolution possible from each mapping technique (see "Decision System for Assigning Zones and Habitats" and "List of Zones and Habitats" for resolving ability of each technique). For example, hyperspectral supervised classification can distinguish coral reef/hardbottom from some other benthic features (e.g. submerged vegetation, sediment, etc.) but, unlike visual photointerpretation, cannot discriminate between discrete types of coral formations such as patch or spur and groove reefs. Furthermore, users will be encouraged to add information into the GIS if they have more detailed knowledge or data for specific areas. For example, habitat polygons delineated as patch reef using this scheme could be further attributed with species specific information (e.g., Porities sp).

Habitat definitions take both a descriptive as well as empirical approach. Descriptive text will be part of “Description of Zones and Habitats” section and analytical information included in “Decision System for Assigning Zones and Habitats” section. The “Decision System for Assigning Zones and Habitats” section will provide detailed methodologies for map production by either the use of aerial photography or hyperspectral imagery. You will note that the current document has only place-holders for these sections. Decision systems will be based on quantitative and qualitative information (e.g. percent cover, texture, or spectral signatures) in the scanned photograph and hyperspectral data, as well as information from field surveys in the Hawaiian Islands. The “Description of Zones and Habitats” section will provide readable descriptions of habitats for managers and other users less interested in the Decision System methodology.

General Description of the Classification Scheme:

The classification scheme defines benthic communities based on two attributes: large geographic “zones” which are composed of smaller “habitats.” Zone refers only to benthic community location and habitat refers only to substrate and cover type (i.e. structure). Every polygon or group of pixels on the benthic community map will be assigned a habitat within a zone (e.g. sand in the lagoon, or sand on the back reef). Zone indicates polygon location and habitat indicates composition of each benthic community delineated. Combinations of habitat and zone that are analogous to traditionally used terminology are noted in the Description section where appropriate. The zone/habitat approach to the classification scheme was developed by combining fisheries models (concept design by Caribbean Fishery Management Council; K. Lindeman, Environmental Defense; and NOS/Biogeography Team -http://biogeo.nos.noaa.gov/benthicmap/caribbean; http://biogeo.nos.noaa.gov/carib-efh/). In addition the draft Hawaii scheme was formulated by integrating information from Gulko (1998), Holthus and Maragos (1995) Pacific Island classification scheme, Allee et al. (unpublished classification scheme), NOAA (2000), benthic habitat maps previously developed for O’hau (State of Hawaii 1981), Puerto Rico (Kruer, 1995; Reid and Kruer, 1998; Lindeman *et al*,1998), and other coral reef systems (Shepard et al., 1995; Chauvaud et al., 1998; Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute and NOAA, 1998; Mumby *et al*,1998), *in situ* Hawaii benthic habitat data, and preliminary analysis of Hawaiian Island aerial photographs.

Eight mutually exclusive zones were identified between land and open water corresponding to insular shelf and coral reef geomorphology. These zones include: island vertical walls, shoreline/intertidal, lagoon, backreef, reef crest, forereef, bank/shelf, and bank/shelf escarpment. Zone refers only to each benthic community’s location and does not address substrate or habitat types found within a zone. For example, the lagoon zone may include patch reefs, sand, and seagrass beds, however, these are considered structural elements that may or may not occur within the lagoon zone and therefore, are not used to define the zone.

Thirty-six distinct habitats (e.g. sand, coralline algae, patch reef) were identified that could be mapped by aerial photography and possibly hyperspectral imagery in conjunction with human interpretation of the imagery. Habitats or features that cover areas smaller than the one acre MMU for aerial photographs were not considered (e.g. the sand halo surrounding a patch reef is too small to be mapped independently). However, pixel and sub-pixel classifications may be possible using hyperspectral imagery. The finer resolution spatial analyses are a component of the Kanehoe Bay hyperspectral experiments (see http://biogeo.nos.noaa.gov/benthicmap/pacific/ for detailed discussion on Kanehoe Bay hyperspectral experiments). Habitat refers only to each benthic community’s substrate and/or cover type and does not address location. Habitats are defined in a collapsible hierarchy ranging from five broad classes (Emergent Mangroves, Submerged Vegetation, Unconsolidated Sediment, Coral/Hardbottom, and Other), to more detailed categories (e.g. algae, individual patch reefs, etc.), to patchiness of some specific features (e.g. 10-50% cover of macroalgae).

The description of each zone and habitat will include example images (aerial images for zones, both underwater and aerial images for habitats). Following the description section, a decision system will be provided (***you will note that ONLY place holders are provided at this time) for assigning zones and habitats including detailed methods for benthic community identification using each mapping technique; visual interpretation of both the aerial photographs and the hyperspectral imagery along with the classification using algorithms based on spectral signatures of particular habitats.

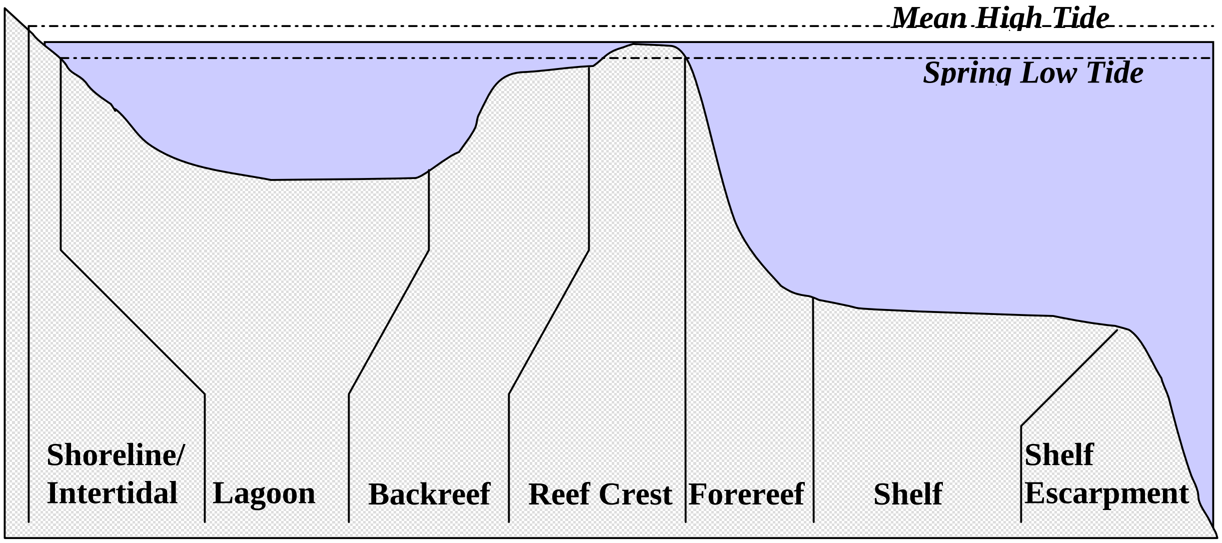
List of Zones and Habitats:

ZONES

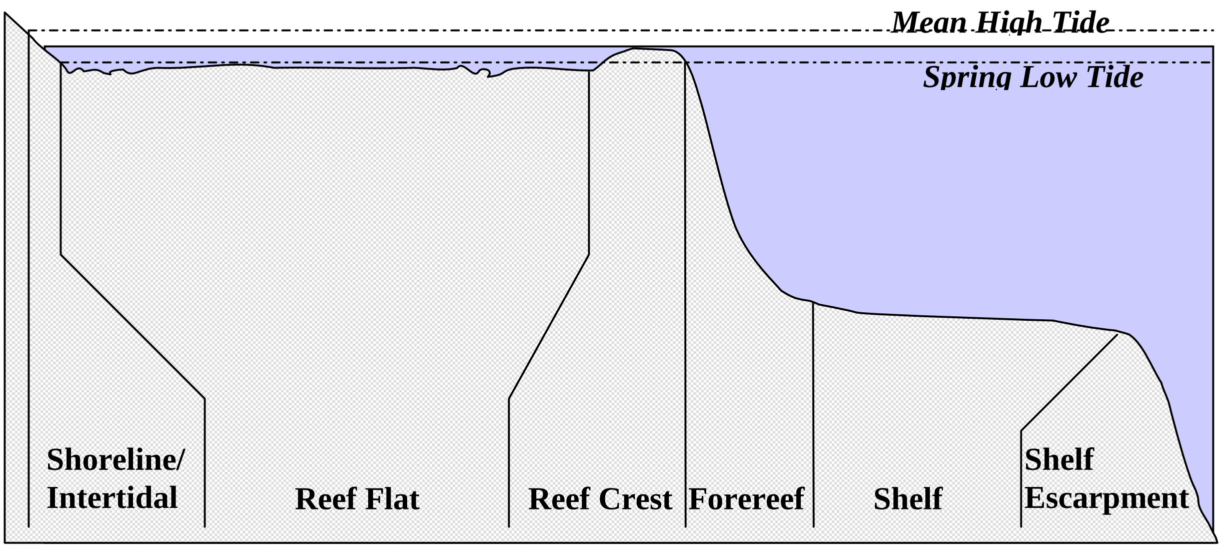
Island Vertical Wall
Shoreline Intertidal
Lagoon
Reef Flat (w/o Lagoon, see fringing reef figure)
Back Reef (w/ Lagoon, see barrier reef figure)
Reef Crest
Fore Reef
Shelf
Shelf Escarpment
Unknown

Conceptual Cross-section of Zones and Other Features:

Barrier Reef System



Fringing Reef System



All, some, or one zone, may be present for any particular area.

HABITATS

Unconsolidated Sediments (0%-<10% submerged vegetation)
- **Sand**
- **Mud**

Submerged Vegetation
- **Seagrass**
  - **Continuous Seagrass (90%-100% Cover)**
  - **Patchy (Discontinuous) Seagrass (50%-<90% Cover)**
  - **Patchy (Discontinuous) Seagrass (10%-50% Cover)**
- **Macroalgae (fleshy and turf)**
  - **Continuous Macroalgae (90%-100% Cover)**
  - **Patchy (Discontinuous) Macroalgae (50%-<90% Cover)**
  - **Patchy (Discontinuous) Macroalgae (10%-<50% Cover)**

Coral Reef and Hardbottom
- **Coral Reef and Colonized Hardbottom**
  - **Linear Reef**
  - **Spur and Groove**
  - **Patch Reef (Individual)**
  - **Patch Reef (Aggregated)**
  - **Scattered Coral/Rock in Unconsolidated Sediment**
  - **Coral Head (Individual)**
  - **Coral Head (Aggregated)**
  - **Colonized Pavement**
  - **Colonized Volcanic Rock/Boulder**
  - **Colonized Pavement with Sand/Surge Channels**
  - **Colonized Island Vertical Walls**
- **Uncolonized Hardbottom**
  - **Reef Rubble**
  - **Uncolonized Pavement**
  - **Uncolonized Volcanic Rock/Boulder**
  - **Uncolonized Pavement with Sand Channels**
  - **Uncolonized Island Vertical Wall**
- **Encrusting/Coralline Algae**
  - **Continuous Encrusting/Coralline Algae (90%-100% Cover)**
  - **Patchy (Discontinuous) Encrusting/Coralline Algae (50%-<90% Cover)**
  - **Patchy (Discontinuous) Encrusting/Coralline Algae (10%-<50% Cover)**

Other Delineations
- **Land**
- **Mangrove**
- **Artificial**
- **Dredged**
- **Cultural**
- **Military**
- **Ship Groundings**
- **Unknown**

Example Sections (note: Hawaii specific photos will be included when available)

Descriptions and Examples of Zones and Habitats:

Geomorphology

Fringing Reef: Reef platform continuous with the shore.

Barrier Reef: Reef separated from the shore by a relatively wide, deep lagoon.

Atoll: Reef surrounding a lagoon. (definition included for comparison)

Zones

Island Vertical Wall: Area with near-vertical decline from shore to shelf or shelf escarpment. This zone is typically narrow and may not be distinguishable in aerial photography.

Typical Habitats: volcanic rock, algae, coral.

Shoreline Intertidal: Area between the mean high water line (or landward edge of mangroves when they are present) and lowest spring tide level (does not include emergent segments of barrier reefs).

Typical Habitats: Mangrove, sand beach, very shallow sand and seagrass, and colonized and uncolonized volcanic/carbonate rock.

Lagoon: Shallow area (relative to the deeper water of the shelf) between the shoreline intertidal zone and the back reef of a reef or a barrier island. This zone is protected from the high-energy waves commonly experienced on the shelf and reef crest. If no reef crest is present there is no lagoon zone.

Typical Habitats: Sand, seagrass, algae, pavement, volcanic/carbonate rock, and patch reefs.

Reef Flat: Shallow (semi-exposed) area between the shoreline intertidal zone and the reef crest of a fringing reef. This zone is protected from the high-energy waves commonly experienced on the shelf and reef crest. Reef flat is typically not present if there is a lagoon zone.

Typical Habitats: Sand, reef rubble, seagrass, algae, and patch reef.

Back Reef: Area between the seaward edge of a lagoon floor and the landward edge of a reef crest. This zone is typically present when a reef crest and lagoon exists.

Typical Habitats: Sand, reef rubble, seagrass, algae, linear reef, and patch reef.

Reef Crest: The flattened, emergent (during low tides) or nearly emergent segment of a reef. This zone lies between the back reef and fore reef zones. Breaking waves will often be visible in aerial images at the seaward edge of this zone.

Typical Habitats: Reef rubble, algal ridge, and linear reef.

Fore Reef: Area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform.

Typical Habitats: Linear reef and Spur and Groove.

Shelf: Deep water area (relative to the shallow water in the lagoon) extending offshore from the seaward edge of the fore reef to the beginning of the escarpment where the insular shelf drops off into deep, oceanic water. The Shelf is the flattened platform between the fore reef and deep open ocean waters or between the shoreline/intertidal zone and open ocean if no reef crest is present.

Typical Habitats: Sand, patch reefs, algae, seagrass, linear reef, colonized and uncolonized pavement, colonized and uncolonized pavement with sand channels, and other coral reef habitats.

Shelf Escarpment: The edge of the shelf where depth increases rapidly into deep, oceanic water. This zone begins at approximately 20 to 30 meters deep, near the depth limit of features visible in aerial images. This zone extends well into depths exceeding those that can be seen on aerial photographs and is intended to capture the transition from the shelf to deep waters of the open ocean.

Typical Habitats: Sand, linear reef, and spur and groove.

Habitats: (***aerial and underwater images will be added in subsequent drafts***)

Unconsolidated Sediments: Unconsolidated sediment with <10% cover of submerged vegetation.

Mud: Fine sediment often associated with river discharge and buildup of organic material in areas sheltered from high-energy waves and currents.

Sand: Coarse sediment typically found in areas exposed to currents or wave energy.

Submerged Vegetation: Greater than 10% cover of submerged vegetation in unspecified substrate type (usually sand, mud, or hardbottom).

Seagrass: Habitat with 10% or more cover of seagrass (e.g., *Halophila sp.*).

Continuous Seagrass: Seagrass covering 90% or more of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (<MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).

Patchy Seagrass: Discontinuous seagrass with breaks in coverage that are too diffuse or irregular, or result in isolated patches of seagrass that are too small (smaller than the MMU) to be mapped as continuous seagrass.

Patchy Seagrass (50%-90% cover)
Patchy Seagrass (10%-50% cover)

Representative Species:
Halophila sp.

Macroalgae: An area with 10% or greater coverage of any combination of numerous species of red, green, or brown macroalgae (e.g., fleshy & turf). Usually occurs in shallow backreef and deeper waters on the bank/shelf zone.

Continuous Macroalgae: Macroalgae covering 90% or greater of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (<MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).

Patchy Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of macroalgae that are too small (smaller than the minimum mapping unit) to be mapped as continuous macroalgae.

Patchy Macroalgae (50%-<90% cover)
Patchy Macroalgae (10%-<50% cover)

Representative Species:
Dictyosphaeria spp.
Halimeda spp.

Coral Reef and Hardbottom: Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock.

Coral Reef and Colonized Hardbottom: Substrates formed by the deposition of calcium carbonate by reef building corals and other organisms. Habitats within this category have some colonization by live coral, unlike the **Uncolonized Hardbottom** category.

Linear Reef: Linear coral formations that are oriented parallel to shore or the shelf edge. These features follow the contours of the shore/shelf edge. This category is used for such traditional terms as fore reef, fringing reef, and shelf edge reef.

Spur and Groove: Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief (relative to pavement with sand channels, see below) and are separated from each other by 1-5m of sand or bare hardbottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the fore reef or bank/shelf escarpment zone.

Patch Reef(s): Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge.

Individual patch reef: Distinctive *single* patch reefs that are larger than or equal to the MMU.
Aggregate patch reefs: *Clustered* patch reefs that individually are too small (smaller than the MMU) or are too close together to map separately.
Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e. smaller than “individual patch reef”).

Coral Head(s): Large coral heads that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. This category may be mapped even if smaller than the MMU.
Individual coral head: Distinctive *single* coral heads that are larger than or equal to the MMU.
Aggregate coral heads: Clustered coral heads that individually are too small (smaller than the MMU) or are too close together to map separately.

Colonized Pavement: Flat, low-relief, solid volcanic/carbonate rock with coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that are dense enough to begin to obscure the underlying carbonate rock.

Colonized Volcanic Rock: Exposed (nearshore) volcanic rock that has coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that begins to obscure the underlying rock.

Colonized Pavement with Sand/Surge Channels: Habitat having alternating sand and colonized pavement (see above) formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand/surge channels of this feature have low vertical relief (relative to Spur and Groove formations). This habitat type occurs in areas exposed to moderate wave surge such as the bank/shelf zone.

Representative Species/Live Coral Community:
Porites compressa
Porites lobata
Montipora spp.
Pocillopora meandrina

Colonized Vertical Island Walls: Unique habitat that some low-light coral and bryozoans colonize along the vertical walls of island shorelines.

Uncolonized Hardbottom: Hard substrate composed of relict deposits of calcium carbonate or exposed volcanic rock.

Reef Rubble: Dead, unstable coral rubble often colonized (but not always) with filamentous or other macroalgae. This habitat often occurs landward of well developed reef formations in the reef crest or back reef zone.
Uncolonized Pavement: Flat, low relief, solid volcanic/carbonate rock that is often covered by a thin sand veneer. The pavement’s surface often has *sparse* coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that does not obscure the underlying volcanic/carbonate rock.

Uncolonized Volcanic Rock/Boulder: Exposed volcanic rock that has s*parse* coverage of macroalgae, hard coral, zoanthids and other sessile invertebrates that does not obscure the underlying rock.

Uncolonized Pavement with Sand Channels: Habitat having alternating sand and uncolonized pavement (see above) formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels of this feature have low vertical relief (relative to Spur and Groove formations). This habitat type occurs in areas exposed to moderate wave surge such as the shelf zone.

Uncolonized Vertical Island Walls: Unique habitat along the vertical walls of island shoreline.

Encrusting/Coralline Algae: An area with 10% or greater coverage of any combination of numerous species of red (dominant), green, or brown macroalgae. May occur in shallow backreef, relatively shallow waters on the shelf zone, and at depth.
Continuous Encrusting/Coralline Algae: encrusting/coralline algae covering 90% or more of the substrate.

Patchy Encrusting/Coralline Algae: Discontinuous encrusting/coralline algae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of coralline algae that are too small (smaller than a MMU) to be mapped as continuous coralline algae.

Patchy Encrusting/Coralline Algae (50%-<90% cover)
Patchy Encrusting/Coralline Algae (10%-<50% cover)

Representative Species:
Porolithon gardineri

Other Delineations:

Mangrove: Emergent habitat composed of primarily of *Rhizophora mangle* (red mangrove). Mangroves are generally found in areas sheltered from high-energy waves. This habitat type is usually found in the shoreline/intertidal or barrier reef crest zone.

Artificial: Armored shoreline such as seawalls, submerged or emergent wrecks, dredge spoil, and other man-made habitats.

Dredged: Excavated or dredged areas typically with sand or mud bottom.

Cultural: Include anchialine ponds and active and remnant fish ponds. Anchialine ponds are natural formations distinctly inland of the shore. Water levels rise and fall with the tide through porous lava. Remnant and active fish ponds are walled off from the open ocean along the shoreline, often along a reef crest.
Military: Areas used for military operations which are normally restricted to other activities.

Ship Groundings: ???

Unknown: Bottom type unknown due to turbidity, cloud cover, or other interference.

Decision System for Assigning Zones and Habitats

Note that this is only a place holder for this section. Detailed information will be included in this section in subsequent drafts

1. Visual Interpretation of scanned photographs.

Description of the method and hierarchical classification level expected to be reached with this method. Error tolerance analysis and method.

2. Visual Interpretation of digital hyperspectral imagery.

Description of the method and hierarchical classification level expected to be reached with this method. Error tolerance analysis and method.

3. Supervised hyperspectral Classification: Image analysis software applied to hyperspectral imagery

Description of the method and hierarchical classification level expected to be reached with this method. Both pixel and sub-pixel analysis will be undertaken.
Error tolerance analysis and method.

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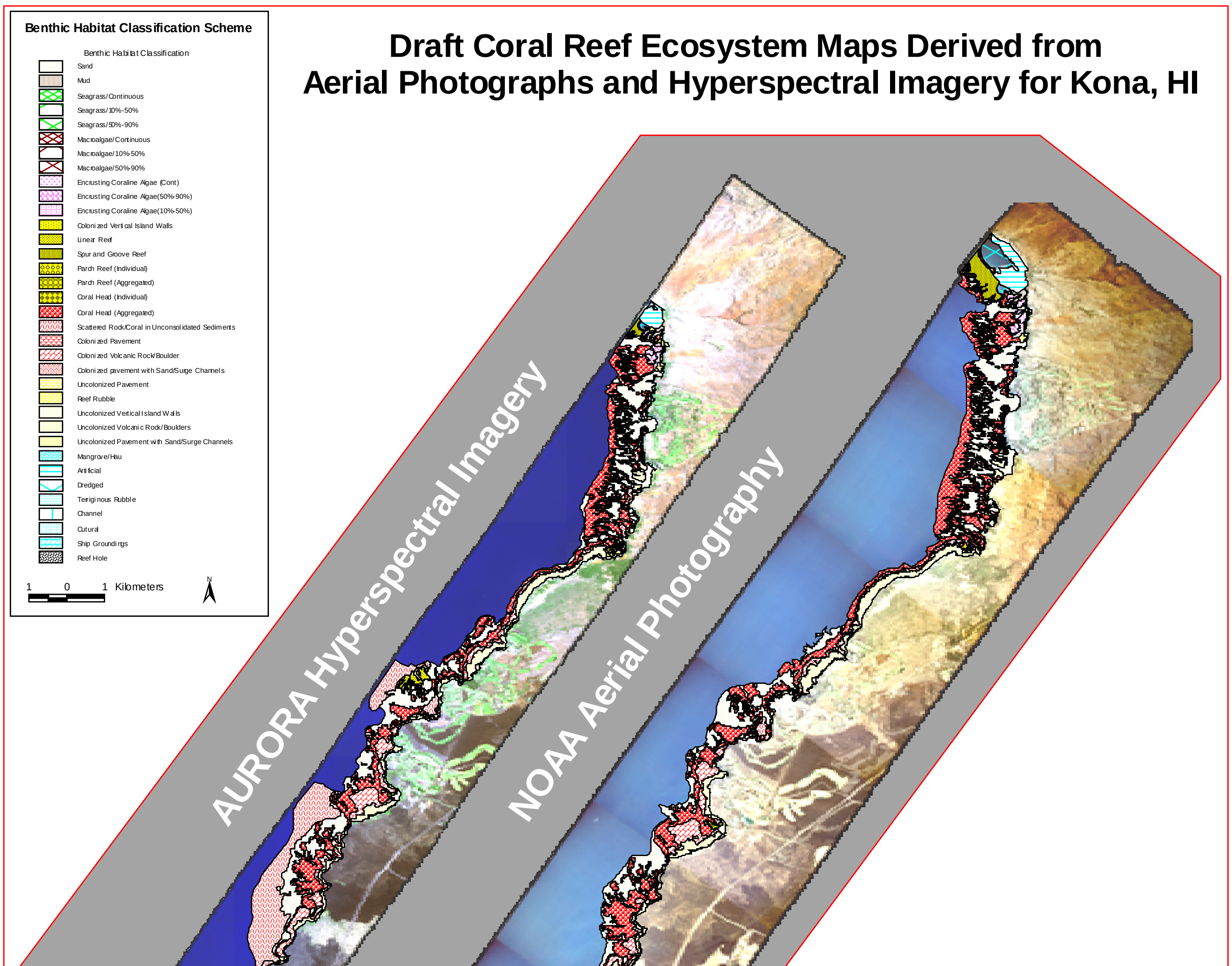
Scanned NOAA Aerial Photography for the Main Eight Hawaiian Islands:

Approximately 551 of the 1500 available photographs for the main eight Hawaiian Islands were selected for coral mapping. This subset of photographs was determined to be suitable for mapping approximately 37 habitat types. The photographs were digitally scanned at 500 dpi for registration and orthorectification using softcopy photogrammetry software. All photographs will be made publicly available Spring 2001 on the NOAA Biogeographic Program internet site at http://biogeo.nos.noaa.gov/products/data/photos.

Benthic Habitat Maps for Kaneohe Bay and Kona Test Areas in the Hawaiian Islands

The color aerial photography and hyperspectral imagery acquired by NOAA's National Ocean Service for the nearshore waters of eight main Hawaiian Islands will be used to create maps of the region's marine resources including coral reefs, seagrass beds, and othe economically important habitats. Accurate maps are necessary for resource managers to make informed decisions about the protection and management of these resources. A primary product of this effort will be a benthic habitat map and a geographic information system produced through manual delineation of the aerial photographs and hyperspectral imagery. Benthic features will be classified using a hierarchical classification scheme and a custom ArcView Habitat Digitizer Extension. A comparative analysis of the accuracy of habitat mapping by color aerial photography and hyperspectral data was conducted in two test areas- Kaneohe Bay, Oahu and Kona, Hawaii.



Accuracy of Interpretation

Statistic	Aerial Photographs	Hyperspectral
Overall Accuracy Detailed Habitat Types (n=37)	83.8%	80.8%
Overall Accuracy Major Habitat Types (n=7)	91.9%	90.3%
Kappa Analysis	0.85%	0.83%

Kona Final Report DRAFT

Benthic Habitats of the Hawaiian Islands

A comparison of accuracy of digital maps prepared from color aerial photography and hyperspectral imagery on the Kona Coast

Prepared for:

National Ocean Survey and National Geodetic Survey

NOAA/NOS/NCCOS NSCI-1

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Outline

I. Introduction and Background

II. Approach

- A. Development of the Hawaii Benthic Habitat Classification Scheme
- B. Habitat Map Accuracy Validation
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- D. Methods
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- B. Spatial Data Quality
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- D. Observer Objectivity
- E. Remote Sensing Data
- F. Benthic Habitat Map Preparation

III. Results

- A. Accuracy Validation Data Collection
- B. Benthic Habitat Map Preparation
- C. Comparison of Results

IV. Discussion

V. Conclusion

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I. Introduction and Background

NOAA's National Ocean Service (NOS) and National Geodetic Survey (NGS) has acquired aerial color and hyperspectral photography for the nearshore waters of the eight main Hawaiian Islands. The images will be used to create maps of the region's marine resources including coral reefs and other important habitats for fisheries, tourism and other aspects of the coastal economy. Accurate habitat maps are necessary for resource managers to make informed decisions about the protection and use of these areas. Analytical Laboratories of Hawaii (ALH) has been contracted to provide mapping and other services to meet the goals of this project.

A primary product of this effort is a benthic habitat map and geographic information system produced by interpreting the remotely collected image data. These benthic habitat maps have been produced by manual delineation of habitats from aerial photographs and image analysis software applied to color and hyperspectral digital images. In both cases, benthic features have been classified using a hierarchical Coral Reef Habitat Classification Scheme. The scheme has been prepared from consultation, meetings and workshops that included the key coral reef biologists and mapping experts and professionals in the State of Hawaii.

The integrated component of the resulting methodology has been developed from a comparative analysis of the accuracy of habitat mapping by color imagery combined with hyperspectral data. These results will be applied in the mapping of the remaining coastlines of the Main Hawaiian Islands.

This part of the pilot study includes the Kona Coast in the District of South Kohala on the west side of the island of Hawaii from Kawaihae Harbor to Kiholo Bay and from shore to a depth of 60 feet. Mapping and collection of accuracy validation data have been completed for both study areas and the results of this work are presented here.

II. Approach

A. Development of the Hawaii Benthic Habitat Classification Scheme

A hierarchical classification scheme has been developed to define and delineate coral reef benthic habitats and reef zones. The draft classification scheme was influenced by many factors including but not limited to:

1. Requests of the management community
2. NOS's coral reef mapping experiences
3. Existing classification schemes for the Pacific and Hawaiian Islands and other coral reef ecosystems
4. Quantitative habitat data for the Hawaiian Islands
5. Minimum mapping unit of one acre and anticipated limitations of the data

Most important, if a feature (e.g., habitat) cannot be detected or seen in the photographs or hyperspectral imagery or classified by its spectral signature, it is not included in the scheme.

The major habitats for the scheme that has been developed for the eight main Hawaiian Islands include:

- Unconsolidated Sediments
  - Sand
  - Mud
- Submerged Aquatic Vegetation
  - Macroalgae
  - Seagrass
- Coral Reef and Hard Bottom
  - Coral Reef and Colonized Hard Bottom
  - Uncolonized Hard Bottom
  - Encrusting/Coralline Algae

These have been subdivided to include a total of 36 habitats that comprise the detailed coral reef benthic habitat classification system for the eight main Hawaiian Islands. These include:

- Unconsolidated Sediments
  - Sand
  - Mud
- Submerged Aquatic Vegetation
  - Macroalgae (fleshy or turf)
    - Continuous Macroalgae (90%-100% Cover)
    - Patchy (Discontinuous) Macroalgae (50%-<90% Cover)
    - Patchy (Discontinuous) Macroalgae (10%-<50% Cover)
  - Seagrass
    - Continuous (90%-100% Cover)
    - Patchy (Discontinuous) Seagrass (50%-<90% Cover)
    - Patchy (Discontinuous) Seagrass (10%-<50% Cover)
- Coral Reef and Hard Bottom
  - Coral Reef and Colonized Hard Bottom
    - Linear Reef
    - Spur and Groove
    - Patch Reef (Individual)
    - Patch Reef (Aggregated)
    - Scattered Rock and Coral in Unconsolidated Sediment
    - Coral Head (Individual)
    - Coral Head (Aggregated)
    - Colonized Pavement
    - Colonized Volcanic Rock/Boulder
    - Colonized Pavement with Sand/Surge Channels
    - Colonized Island Vertical Walls

- Uncolonized Hard Bottom
  - Reef Rubble
  - Uncolonized Pavement
  - Uncolonized Volcanic Rock/Boulder
  - Uncolonized Pavement with Sand Channels
  - Uncolonized Island Vertical Wall
- Encrusting/Coralline Algae
  - Continuous Encrusting/Coraline Algae (90%-100% cover)
  - Patchy (Discontinuous) Encrusting/Coralline Algae (50%-<90% cover)
- Patchy (Discontinuous) Encrusting/Coralline Algae (10%-<50% cover)

Other Delineations
- Land
- Mangrove/Hau
- Artificial
- Dredged
- Cultural
- Military
- Terriginous Rubble
- Ship Groundings
- Unknown

The Zones have been developed as:

Island Vertical Wall
- Shoreline Intertidal
- Reef Flat
- Back Reef
- Reef Crest
- Fore Reef
- Shelf
- Shelf Escarpment

Unknown

B. Habitat Map Accuracy Validation

Recognizing that the purpose of this study is to determine the relative accuracy of maps generated from photointerpretation of aerial color photography and hyperspectral imagery, a photointerpretation accuracy assessment system has been designed and executed to quantify this comparison. For the purpose of validation of the photointerpretation, methods have been applied that have been developed by other researchers (Hudson and Ramm 1987, Congalton, 1991). Rosenfield et al. (1982) have also determined that a statically valid data set, at 90% to 95% confidence interval is obtained where at least 50 field habitat observations have been obtained per major habitat type. The accuracy assessment is generated from a matrix that compares the habitat assigned to a polygon generated from the interpretation of the image with that of the determination from field observation. Traditionally, the data is organized into columns that represent the field habitat validation data and the rows are organized into the interpretation of the images. The overall accuracy is typically measured by dividing the total correct determinations by the total number of assessments. This result only incorporates the major diagonal of the table and excludes the omission and commission errors where as the Kappa analysis (Cohen, 1960) indirectly incorporates the off-diagonal elements as a product of the row and column marginals. This assessment lends itself to statistical analysis wherein the probability of the photointerpreter's determination is assigned a probability that it occurred at random.

The assessment of determining the accuracy of photointerpretation of each habitat type is conducted in a similar way. However, this introduces the possibility of comparing the number correct by dividing by the total of the column (producer's accuracy) or dividing by the total of the row (user's accuracy). In this assessment both analysis methods have been employed. It is however recognized that the producer's accuracy has been indicative of how well a certain area can be classified (the probability of a reference pixel being correctly classified). Therefore, for the purposed of this analysis, it is suggested that producer's accuracy be considered the most representative of the two methods.

A Coral reef benthic habitat field validation assessment has been completed for the Kona pilot study area as ground truth to establish the accuracy of maps produced from aerial color photography and hyperspectral image interpretation. An attempt to collect at least fifty points within the major habitat categories that existed in the study area was made.

C. Habitat Map Preparation

Traditional methods of "grease pencil" delineation of photointerpreted habitat classes has been nearly completely replaced by computerized "heads up" digitizing methods. These latter methods lend themselves to distinct advantages. While productivity is higher, by developing an active link between the mapped image and the associated database, a Geographic Information System (GIS) is generated. The applications of GIS provide a powerful analytical tool that yields critical information and contributes to the ability of making sensible long-term natural resource management plans. The maps and mapping methods described in this report were developed using Environmental Systems Research Corporation (ESRI) ArcView GIS software.

III. Methods

A. Accuracy Validation Data Collection

A random geographic referenced point file was created for both the Kaneohe Bay and Kona pilot study areas (Figures 1 and 2). This was done using a random point generator obtained from the ESRI web site. The software generates random points inside an ArcView GIS polygon shape. A polygon of the study area was digitized from a georeferenced NOAA navigational chart and a coastline shape file obtained from the Hawaii Department of Aquatic Resources GIS web site. These were projected in the appropriate UTM Zone on WGS 84 datum and MSL altitude. The extent of the Kona study area polygon included the north end of Kawaihae Harbor to the south end of Kiholo Bay and from shore to a depth of 60 feet.

Three sets of random points were generated within the polygon of the Kona study area. The first set contained 200 points and the second and third each contained 100 points. Point and area benthic habitat assessments were conducted at each location in the first set. Upon completion of the first set, the data were examined and habitat types that needed additional surveys were identified. The second and third sets of points were subset to meet these needs and 304 benthic habitat assessments were completed.

Waypoint files were generated and all points that could be safely accessed were navigated to using a Trimble GeoExplorer 3 GPS data logger. Upon arriving at the waypoint, a weighted meter line was dropped and a buoy fastened. Three benthic habitat assessments were conducted. A point assessment was conducted by surveying the 1 square meter area around the point where the weight dropped. Two area assessments were conducted in an area of a seven-meter radius around the weight. The first assessment identified the most common habitat type within the area and the second identified the second most common habitat type with in the area.

The depth of the site was recorded and the benthic habitat assessment was made using a glass bottom look box, diving or observing from the surface. In areas where waves and sea conditions were prohibitive to using these methods, the GPS was placed in a watertight box and swam to the survey point.

All point data were recorded on the GPS data logger using a custom data dictionary designed to meet the specifications of the Coral Reef Habitat Classification Scheme. Area data were entered in waterproof notebooks and transferred to the GIS by hand. Extensive underwater video was collected and video capture was used to create a visual record of habitat types.

B. Spatial Data Quality

Upon arriving at a waypoint, and deployment of the buoyed lead line, GPS logging began. One hundred GPS positions were collected at 1-second intervals for each survey site. The positions were averaged to obtain a single survey point. The data were post processed for differential correction.

Data were collected to determine spatial accuracy. Each day a GPS position was collected at the pier at Kawaihae Harbor and several others were collected at jetty markers and other monuments.

C. Points of Interest

When an area was encountered where particularly interesting or uncommon habitat was visited, benthic habitat assessments were conducted that were not included in the random point set. These were assigned letters to distinguish them from the random point assessments, which were assigned numerical site identifiers.

D. Observer Objectivity

The Coral Reef Assessment and Monitoring Program (CRAMP) team made all benthic habitat decisions independent of the ALH contractor. During the habitat assessments, the ALH contractor made observations regarding the features in aerial photography and the corresponding habitat types in the field to enhance skills in aerial photointerpretation of these benthic habitats. Furthermore, the CRAMP team independently conducted the assessment of the extent to which the photointerpretation met the field assessment determinations. These data were then used to prepare the comparison of the ability to photointerpret benthic habitat types from aerial photography and hyperspectral imagery.

E. Remote Sensing Data

Technological advances have been made that offer powerful image analysis alternatives and state-of-the-art methods have been employed in this study. Both aerial photographic data and digital hyperspectral imagery were collected by NOAA using instrumentation installed onboard the dual port NOAA AOC Citation II aircraft. The color aerial photography was provided to the contractor as discrete georeferenced images in Geo TIFF format scanned at a resolution of one-meter pixel. These were imported to ArcView GIS software using the ESRI Image Analysis extension where manual habitat delineation was conducted.

The hyperspectral image (HSI) data were collected by the AURORA Hyperspectral Imaging System. Navigation data was incorporated using the Applanix inertial navigation system (INS). The camera collects seventy-two 10 nm bands in the visible and near infrared spectral range per pixel with the pixel size at 3 meters. The raw data was provided to the contractor along with the navigational data and spectral processing was conducted using Research Systems, Inc. ENVI software. Optimum band combinations were selected which reveal benthic habitat information and the scenes were converted into RGB composites. The scenes were then georeferenced to UTM Zone 4 on NAD 83 datum and mosaiced using Scene Stitcher, a stand-alone software program produced by Applied Power Technologies, Inc. (APTI). The mosaics were then imported to the ArcView GIS system where manual delineation of habitat boundaries was undertaken based on photointerpretation.

F. Benthic Habitat Map Preparation

The coral reef benthic habitat maps of the study area have been digitized by delineating photointerpreted habitat boundaries from the imagery provided to the contractor by NOAA. As ESRI ArcView GIS software has been used in the preparation of the maps, NOAA staff have developed an editable ArcView extension that allows for a custom habitat classification scheme to be developed based on the user's needs. The software also allows for zone classifications to be included and toggles between the legends of the habitats and zones within the GIS system. This extension was used in the preparation of the maps presented here.

NOAA supplied georeferenced color photography of the Kona survey site to ALH. The georeferenced digital photos were provided as discrete non-mosaiced files. This format allowed the contractor to substitute individual images to take advantage of optimal visibility of reef features and extract the most habitat information. The raw hyperspectral data were processed by the contractor as described above and habitat maps were then produced using the same methods used to generate habitat maps from the color aerial photography.

All delineation of habitat boundaries was conducted with the image scale at 1:6,000. This ensures that the level of detail produced by the photointerpreter is uniform throughout the project. Also, NOAA has shown from similar mapping efforts in the Caribbean and Gulf of Mexico, that little additional information is gained from having the image at a closer scale and the labor intensity increased significantly. Similar logic has been used to determine the Minimum Mapping Unit (MMU) of 1 acre. The ArcView digitizing extension described above provides the option of setting the MMU area. It informs the photointerpreter when a polygon is being closed that has an area below that selected and provides the option of including or eliminating that polygon. These standards ensure a uniform mapping product.

Comparison of the photointerpretation of the two types of remotely sensed data has been conducted. Discrete multivariate analysis has been applied to the results, as have other simple comparisons of correct vs. incorrect calls.

IV. Results

A. Accuracy Validation Data Collection

A total of 305 GPS positions were recorded during the accuracy validation data acquisition of the Kona study area (Figure 1). These include the random points, control points and areas of interest. As the details of the habitat data are too extensive to present here, summaries have been made below. An ArcView shape file and Excel spreadsheet containing the details of these data are included on the enclosed CD-ROM. All data were collected as planned.

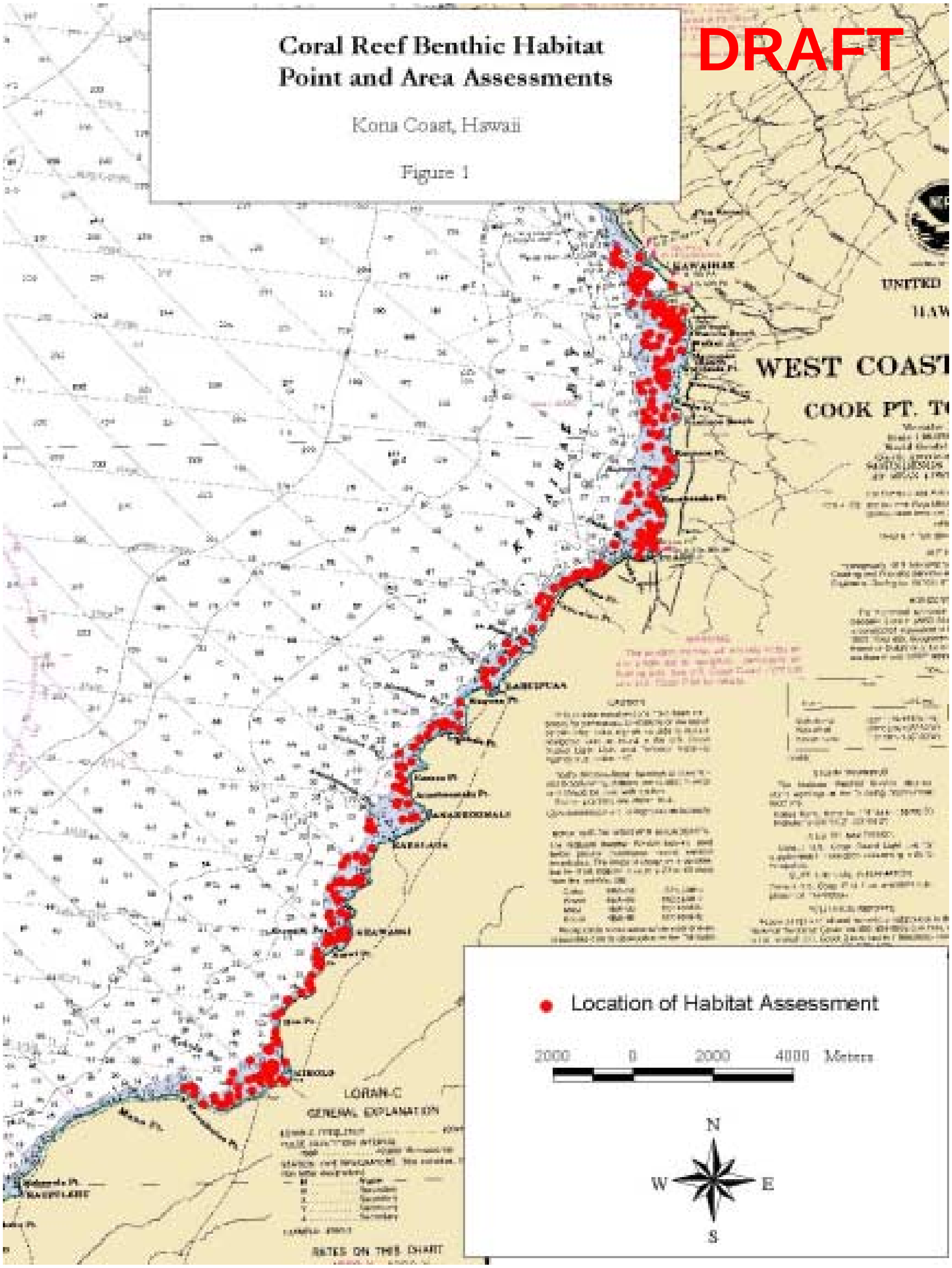
B. Benthic Habitat Map Preparation

Habitat maps were prepared from both color aerial photography and hyperspectral imagery and samples of the habitat maps are presented (Figures 2 and 3). These maps are also included on the enclosed CD-ROM in GIS format. The extent of correct vs. incorrect habitat interpretations is also presented and is organized to illustrate the extent of correctness of photointerpretation of coral reef habitat types for both detailed and major habitat classifications. Validation of photointerpretation of detailed coral reef habitats using color aerial photography and hyperspectral data are presented (Tables 1 and 2). Validation of photointerpretation of major coral reef habitats using color aerial photography and hyperspectral are also presented (Tables 3 and 4).

These tables have been summarized along with the Kappa Statistic (KHAT) for the major habitat types (Table 5) providing a simple overview of the estimated accuracy of the two methods at the Kona survey site. From Table 5 it can be seen that the overall accuracy of photointerpretation of detailed coral reef habitats from aerial photography and hyperspectral imagery is 83.3% and 80.8% respectively. It can also be seen that the overall accuracy of photointerpretation of major coral reef habitats from aerial photography and hyperspectral imagery is 91.9% and 90.3% respectively.

C. Comparison of Results

The result of Z analysis, a probability representing the confidence that there is no difference between the accuracy of the maps from photointerpretation of color aerial photography and hyperspectral imagery is also included in Table 5. This overall summary of the two methods shows that there are no differences between the two methods at a 95% level of confidence.


Coral Reef Benthic Habitat
Point and Area Assessments
Kona Coast, Hawaii
Figure 1
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WEST COAST
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LORAN-C
GENERAL EXPLANATION
RATES ON THIS CHART
Location of Habitat Assessment
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Figure 2. North End of Kona Benthic Habitat Map
Based on Photointerpretation of Color Aerial Photography

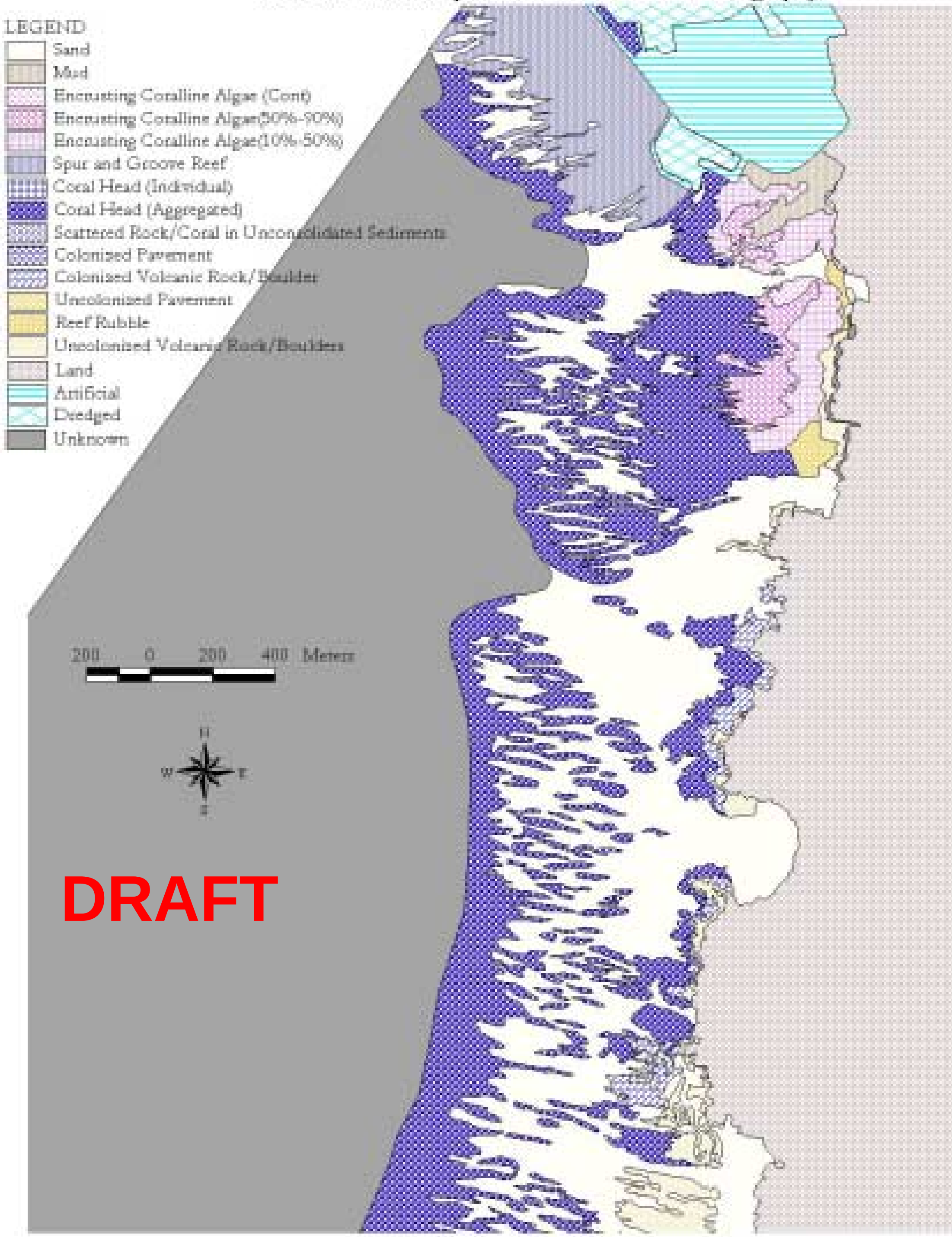

Figure 3. North End of Kona Benthic Habitat Map
Based on Photointerpretation of Hyperspectral Imagery

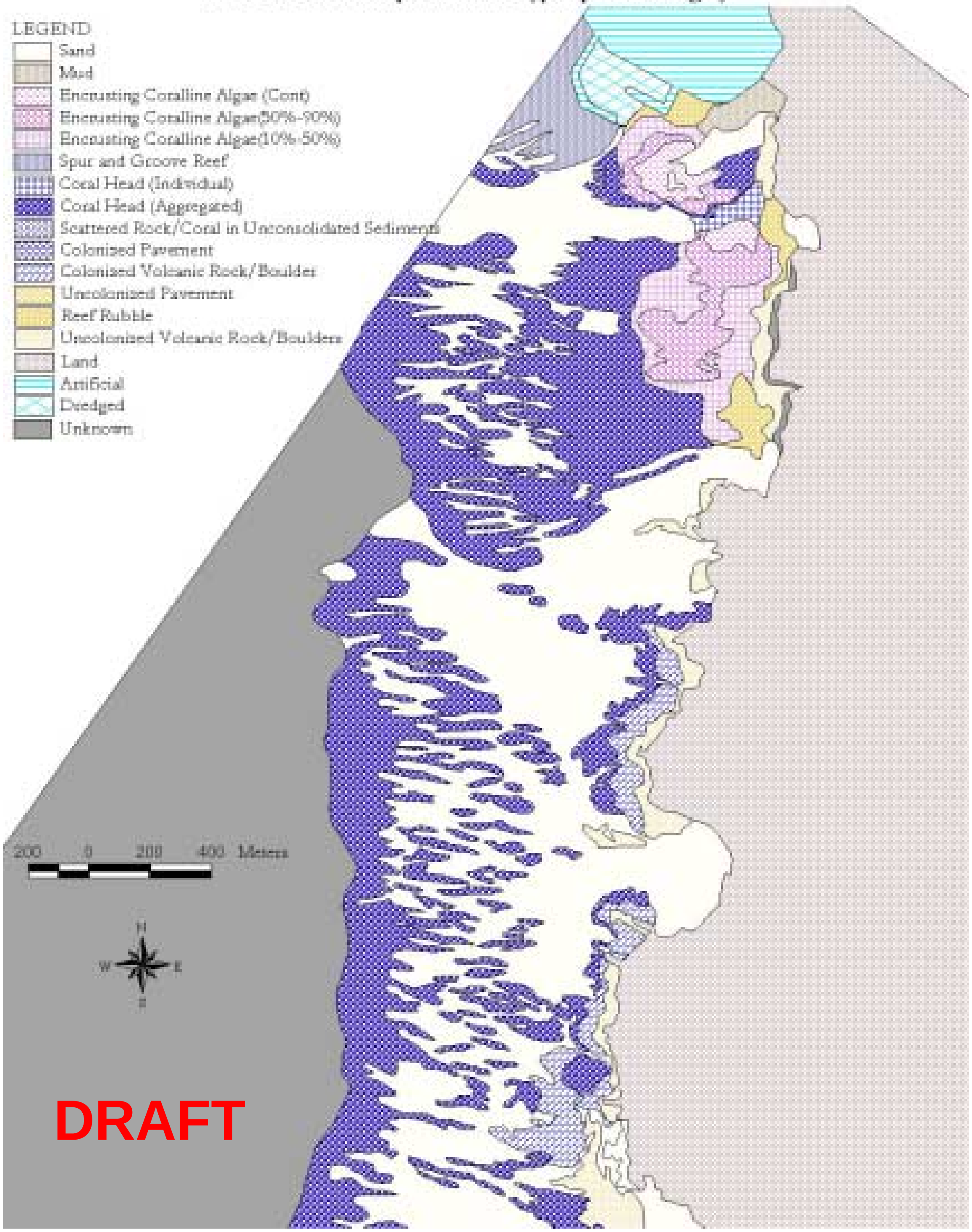

Table 1. Validation of Photointerpretation of Detailed Coral Reef Habitats using Color Aerial Photography from the Kona Survey Site

Color

	Ground Truth Detailed Habitats for Kona Site														Row	Users
	SAND	Mud	SandG	InCr	AgCr	ColPv	ColBa	ColPvSC	UnColBa	LCorAl	MCorAl	HCorAl	Artf	Dredged	**Totals**	Accuracy
SAND	**51**	0	0	0	1	0	0	0	0	0	0	0	0	0	**52**	98%
Mud	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	100%
SandG	0	0	**11**	0	0	0	0	0	0	0	0	0	0	0	**11**	100%
InCr	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	**0**	NA
AgCr	4	0	0	0	**82**	4	16	0	0	0	1	0	0	0	**107**	77%
ColPv	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	**0**	NA
ColBa	3	0	0	2	2	0	**50**	0	2	0	0	0	0	0	**59**	85%
ColPvSC	0	0	0	0	1	0	0	**1**	0	0	0	0	0	0	**2**	50%
UnColBa	0	0	0	0	0	0	4	0	**21**	0	0	0	0	0	**25**	84%
LCorAl	0	0	0	0	1	0	0	0	0	**1**	1	0	0	0	**3**	33%
MCorAl	0	0	0	0	0	0	0	0	0	1	**5**	2	0	0	**8**	63%
HCorAl	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	**0**	NA
Artf	0	0	0	0	0	0	0	0	0	0	0	0	**7**	0	**7**	100%
Dredged	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**	**3**	100%
All Grps	**58**	**1**	**11**	**2**	**87**	**4**	**70**	**1**	**23**	**2**	**7**	**2**	**7**	**3**	**278**	
Producers Accuracy	88%	100%	100%	0%	94%	0%	71%	100%	91%	50%	71%	0%	100%	100%		

Overall Accuracy: 83.8%

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Table 2. Validation of Photointerpretaion of Detailed Coral Reef Habitats using Hyperspectral Imagery from the Kona Survey Site

Hyperspectral

	Ground Truth Detailed Habitats for Kona Site														Row	Users
	SAND	Mud	SandG	InCr	AgCr	ColPv	ColBa	ColPvSC	UnColBa	LCorAl	MCorAl	HCorAl	Artf	Dredged	**Totals**	Accuracy
SAND	**49**	0	0	0	0	0	0	0	0	0	0	0	0	0	**49**	100%
Mud	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	100%
SandG	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	**1**	100%
InCr	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	**0**	NA
AgCr	4	0	0	2	**72**	4	8	0	0	1	1	0	0	0	**92**	78%
ColPv	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	**0**	NA
ColBa	4	0	0	0	6	0	**59**	0	2	0	0	0	0	0	**71**	83%
ColPvSC	1	0	0	0	1	0	0	**1**	0	0	0	0	0	0	**3**	33%
UnColBa	2	0	0	0	1	0	4	0	**21**	0	0	0	0	0	**28**	75%
LCorAl	0	0	0	0	1	0	0	0	0	**1**	2	0	0	0	**4**	25%
MCorAl	0	0	0	0	1	0	0	0	0	1	**1**	3	0	0	**6**	17%
HCorAl	0	0	0	0	0	0	0	0	0	0	2	**0**	0	0	**2**	NA
Artf	0	0	0	0	0	0	0	0	0	0	0	0	**7**	0	**7**	100%
Dredged	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	100%
All Grps	**60**	**1**	**1**	**2**	**82**	**4**	**71**	**1**	**23**	**3**	**6**	**3**	**7**	**1**	**265**	
Producers Accuracy	82%	100%	100%	0%	88%	0%	83%	100%	91%	33%	17%	0%	100%	100%		

Overall Accuracy: 80.8%

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Table 3. Validation of Photointerpretation of Major Coral Reef Habitats using Aerial Photography from the Kona Survey Site

Color Aerial Photo Interpretation Major Habitats	Ground Truth Major Habitats						Total Classified	Users Accuracy
	Unconsol. Sed.	Submerg Aquat. Veg.	Coral Reef & Col HB	Uncol. Hard-bottom	Encrust. Coralline Algae	Other Delin.		
Unconsol. Sediments	**52**	3	1	0	0	0	56	**93%**
Submerged Aquat. Veg.	0	**0**	0	0	0	0	0	**NA**
Coral Reef & Col. HB	8	0	**169**	2	1	0	180	**94%**
Uncolon. Hardbottom	2	0	5	**21**	0	0	28	**75%**
Encrust. Coralline Algae	0	0	1	0	**10**	0	11	**91%**
Other Delineations	0	0	0	0	0	**10**	10	**100%**
Total Ground Truth Points	62	3	176	23	11	10	**285**	**NA**
Producers Accuracy	**84%**	**0%**	**96%**	**96%**	**91%**	**100%**	**NA**	

Overall Accuracy: **91.9%**

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Table 4. Validation of Photointerpretaion of Major Coral Reef Habitats using Hyperspectral Imagery from the Kona Survey Site

Hyperspectral Image Interpretation Major Habitats	Ground Truth Major Habitats						Total Classified	Users Accuracy
	Unconsol Sed	Submerg Aquat Veg	Coral Reef & Col HB	Uncol Hard-bottom	Encrust. Coralline Algae	Other Delin.		
Unconsol. Sediments	**50**	3	0	0	0	0	53	**94%**
Submerged Aquat. Veg.	0	**0**	0	0	0	0	0	**NA**
Coral Reef & Col. HB	10	0	**154**	2	2	0	168	**92%**
Uncolon. Hardbottom	2	0	5	**21**	0	0	28	**75%**
Encrust. Coralline Algae	0	0	2	0	**10**	0	12	**83%**
Other Delineations	0	0	0	0	0	**8**	8	**100%**
Total Ground Truth Points	62	3	161	23	12	8	**269**	**NA**
Producers Accuracy	**81%**	**0%**	**96%**	**91%**	**83%**	**100%**	**NA**	

Overall Accuracy: 90.3%

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Table 5. Summary of Accuracy of Photointerpretaion of Detailed and Major Coral Reef Habitats at the Kona Survey Site

Statistic	Color	Hyperspectral
Overall Accuracy Detailed Habitat Types	83.8%	80.8%
Overall Accuracy Major Habitat Types	91.9%	90.3%
Kappa Analysis	0.85	0.83
Z Analysis	Probability that photointerpretation of coral reef habitat from Color and HSI data are equivalent: P = 0.05 or less	

The GIS maps prepared in this effort have been provided as hard copy output in this report and also as ArcView data on the enclosed CD-ROM. This GIS data is located in the "GIS_Data" directory. Also on the CD-ROM is a directory of selected underwater photos that were taken of representative habitat types within the study area. These are in JPG format to reduce the computer memory required for storage. Each photo includes the unique site ID and habitat type and thus can be referenced to its location in the study area. These have been stored in the CD_ROM in the "UW_Photos" directory.

Other important files have been included in the "Support_Data" directory. They include:

1. Zipped file of habitat digitizing extension including text file of instructions
2. Zipped file of zone digitizing extension including text file of instructions
3. Habitat classification scheme prepared in the habitat map digitizing extension
4. Blank legend habitat file
5. Filled legend habitat file

V. Discussion

Remotely sensed data has been used in developing management strategies for natural resources in terrestrial ecosystems for many years. These same tools are now being applied to mapping and monitoring of living marine resources. Much of this interest is fostered by the escalation of concern of depletion of marine resources on a global scale. As coral reefs are among the most productive of these and are integrated into nearly every aspect of the reproduction, feeding and growth to maturity within the entire ecosystem, remote sensing has been demonstrated to be an invaluable tool. The methods yield vast amounts of habitat related information over large geographic areas. New technology is being developed in ongoing research and development programs that resolve the difficulties encountered when these traditionally terrestrial methods were applied to marine systems. In recent years the utility of advanced spectral processing of imagery has been closely examined. When extracting marine habitat information from traditional color photography, the methods have been primarily limited to photointerpretation. However, with the development of techniques that include a large number of spectral bands from which to choose, the potential to select spectral data that are upwelled from specific habitat types is being realized. Significant progress is being made in reducing the water column effects that have previously interfered with these determinations.

With automated classification of habitat maps from algorithmic processing using spectral libraries being developed, we are still obligated to remain conservative. It is recognized that in a worst case scenario, the least sophisticated method of extracting habitat information from remotely sensed data must be retained until it has been demonstrated to be completely obsolete. Photointerpretaion of “0” level processed data must therefore be retained as an option as the more sophisticated methods are being refined. This study addresses the accuracy with which a photointerpreter delineates coral reef habitat using color aerial photography and RGB composites of 72 band hyperspectral imagery.

Both remotely sensed data sets collected by NOAA for this study site are excellent. Environmental conditions were ideal at the time the data was collected. Wind was light, the sky cloudless, swell size very small and water clarity good. All conditions considered, this was an excellent opportunity to conduct this work with minimal variables. Furthermore, as both data sets were collected simultaneously, many other variables were controlled that would have otherwise introduced uncertainties.

Acquisition of field accuracy assessment data proceeded flawlessly. The Coral Reef Assessment and Monitoring Program (CRAMP) directed by Dr. Paul Jokiel of Hawaii Institute of Marine Biology (HIMB) and supported by Will Smith, a Ph.D. graduate student in the Department of Geography at the University of Hawaii Manoa conducted the habitat assessments. During the field survey, the contractor conducted general observations correlating habitat type with information in the images and managed navigational data quality and data base management.

Both data sets were adequately georeferenced and the mosaic software supplied by APTI stitched the HSI data into a seamless backdrops with specific bands selected to enhance deep water features and a separate set of bands to enhance shallow water features. Production of GIS maps of the benthic coral reef habitat of the Kona coast from both data sets was considerably streamlined by the NOAA ArcView Habitat Digitizing Extension. Throughout the project, the extension was refined and the final version is user friendly and easily modified to meet the demanding requirements of the needs of particular projects.

The CRAMP team conducted validation of the maps based on determination of the correctness of each polygon class judged by the field accuracy assessment data. Several instances occurred where it was apparent that the minimum mapping unit of 1 acre resulted in false negative determinations. This occurs when a random field assessment falls on a habitat area that qualifies for the field assessment of 7 meter diameter but does not qualify for delineation of a GIS polygon as it is less than the as the MMU. In these cases, though the data is not deleted from the database, the assessment was not included in the determination of accuracy.

It will also be noted that the number of points, which were used in the final assessment of accuracy, was 285 for the aerial photography and 269 for the HSI data. The slightly reduced number of points for the HSI survey is a resulted as the extent of the boundary of the HSI data did not include an area of the color photography on the north end of the study area. The statistical analysis was not corrupted by this difference.

Of particular interest is that the HSI data, even at level 0 processing, resolves reef features in deeper water than color photography. This observation is not apparent in the statistical analysis, as the depth of the field survey was limited to 60 feet. Given the water quality conditions during this survey, reef features were distinguishable in water estimated to be 100 feet depth or more in the HSI data. The limitation of color photography was at about 60 feet.

VI. Conclusion

A comparison of accuracy of photointerpretation of color aerial photography and AURORA hyperspectral imagery collected for the Kona Pilot Study Area has been completed. The maps prepared from each of these methods have been compared and the results show conclusively that, for this data set, there is no statistical difference between their accuracy.

VII. References

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Experimental Mapping of Hawaiian Islands' Benthic Habitats Derived From Hyperspectral Imagery:

A Cooperative Investigation Between NOS, the University of Hawaii, and Analytical Laboratories of Hawaii, Inc.

Objectives

In the fall of 2000 NOAA's National Ocean Service (NOS) and the University of Hawaii (UH) entered into a 24 month cooperative agreement to determine if benthic (bottom) habitat maps could be derived using hyperspectral imagery (HSI). In addition, Analytical Laboratories, Inc. is an integral partner in this investigation via a contract with NOS. The objectives of the research are:

1) Obtain a quality hyperspectral database using airborne systems that can be easily georeferenced and have sufficient spectral resolution to map habitats found within Hawaii coral reef ecosystems.
2) Produce benthic habitat maps based on the spectral signatures (reflectance of light) of habitats (e.g., coral, seagrass) using computer algorithms.
3) Evaluate the time, cost, and accuracy of the computer generated maps compared to other mapping technologies such as, visual interpretation of digital photographs.

The Approach

These objectives are being addressed at two pilot study sites: 1) Kanehoe Bay on Ohau, and 2) a portion of the Kona coastline of Hawaii. Kanehoe Bay has the full suite of field-based radiometric (light) measurements. As such, 5 Kaneohe Bay image derived products and associated maps will be generated using various assemblages of the in-situ and ground truthing data ranging from no supporting radiometric data to a complete set of measurements. Accuracy and intercomparison will be conducted for each map using visually interpreted maps of the same areas. The visually interpreted maps have been developed under contract with Analytical Laboratories of Hawaii, Inc (ALH) and these maps are 90% accurate in delineating bottom habitats. These maps were produced in March 2001 and can be used in combination with field groundtruthing data (over 700 points) to assess the accuracy of the computer derived map products. The Kona coastline pilot study site will serve as test a case to determine if we can develop map products from HSI without having a major in-situ effort in other specific regions of Hawaii. Analogous to the work underway in the Caribbean, we have attempted to select pilot study areas the represent most of the habitat types that we will encounter around the main 8 Hawaiian Islands. Thus, the accuracy assessment points will enable evaluation of the visually interpreted and computer generated maps from the hyperspectral imagery.

Level 0-2 Analyses

We have implemented the cooperative mapping research investigation under 3 different level of analyses: Levels 0, 1, and 2.

Level 0. Analyses have been completed by ALH using visual interpretation of digital photography and hyperspectral imagery. NOS provided georeferenced photo mosaics using 1-meter digital orthoquads and georeferenced airborne hyperspectral data for these areas. A final report on the evaluation of the NOS derived benthic habitat classification scheme, ability to georeference the digital photography and HSI, and accuracy of the visual interpretation of both the photographs and HSI will be completed in April 01. The Kona coastline section of this report is completed and both the maps derived from visual interpretation of digital photography and hyperspectral imagery are well georeferenced and overall about 90% accurate in delineating bottom habitats.

Level 2 and 3 analyses are underway at UH and a progress report on this work will be available in May of 01.

Level 1. Analyses by UH will use in-situ data and ground spectra to model habitat distribution and composition. The intent of Level 1 analyses is to develop computer-generated maps for broad levels of habitat classification (e.g., coral reef, seagrass, algae). Also, evaluation of accuracy assessment will be conducted using varying levels of accuracy assessment points (e.g., 50, 100, 250). This evaluation will aid in determining how many ground accuracy assessment data points must be collected to evaluate image interpretation to specific level of acceptance.

Level 2. These analyses will evaluate images and classified map products derived by UH via selection of a training dataset from the hyperspectral images and also by classifying the images using UH algorithms. These analyses will include supervised classification of the maps using in-situ habitat spectra and bottom albedo (reflectance). Finally, computer generated maps using the various approaches will be evaluated to determine the accuracy of each habitat map.

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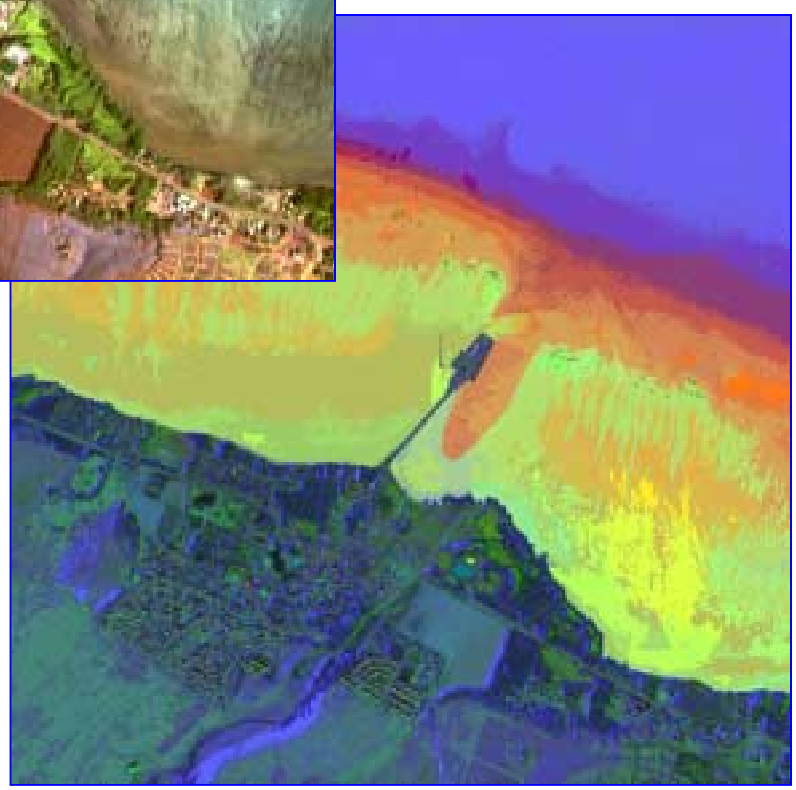
DRAFT FY01/02 NOS BENTHIC HABITAT MAPPING PLAN FOR THE MAIN 8 HAWAIIAN ISLANDS:

AN EVOLVING PARTNERSHIP PROJECT WITH

THE UNIVERSITY OF HAWAII
ANALYTICAL LABORATORIES OF HAWAII, INC
ADVANCED POWER TECHNOLOGIES, INC
THE NATIONAL MARINE FISHERIES SERVICE
US FISH AND WILDLIFE SERVICE
HAWAII DEPT OF LANDS AND NATURAL RESOURCES



BACKGROUND

The 1998 Executive Order on Coral Reef Protection directs Federal agencies to map, research, monitor, manage, and restore coral reef ecosystems. The National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) has several significant projects underway initiative to map, study, and restore US coral reefs. NOS's will conduct research, digitally map biotic resources, and coordinate a long-term monitoring program that would detect and predict change in US coral reefs and associated habitats.

Most US coral reef resources have not been digitally mapped at a scale or resolution sufficient for assessment, monitoring and research to support resource management. A comprehensive coral reef database and GIS will provide the organizing spatial framework to better focus research and monitoring activities in support of natural resource management decisions. Furthermore, the development of mapping technologies based on emerging remote sensing tools may enable more rapid assessments of coral reefs and should evolve to efficient and reliable approaches to monitor the health reef ecosystems.

The Mapping and Information Synthesis Work Group, under NOS leadership, developed a Mapping Implementation Plan (see http://biogeo.nos.noaa.gov/MIP) to map all US Caribbean, Gulf of Mexico, and Pacific coral reefs. The US Coral Reef Task has endorsed the Mapping Implementation Plan and the proposed NOS FY01/02 coral mapping studies directly support the Task Force guidance and objectives.

Objective:

- Map the distribution of US coral reef habitats and associated species.

Targeted Questions:

- What is the spatial extent of US coral reef habitats?
- What is the condition of US coral reefs (e.g., percent healthy or degraded)?
- What coral species comprise US coral reef ecosystems and is coral biodiversity changing?
- How can remote sensing from aircraft and satellite best be implemented for mapping, rapid assessment, and monitoring of characteristics and change in benthic habitats?

MAIN 8 HAWAIIAN ISLANDS CORAL REEF MAPPING

This document focuses only on the mapping of US coral reef ecosystems in FY01/02 in the main eight Hawaiian Islands. Although NOS does not have exact funding figures available for coral mapping in FY 01, the plan anticipates similar or greater funding as in FY 00 to support the NOS-lead investigation. The Hawaii mapping project is conducted in partnership with the University of Hawaii, the Department of the Interior, the National Marine Fisheries Service, Advanced Power Technologies, Inc, Analytical Laboratories of Hawaii, Inc, and the Hawaii Department of Lands and Natural Resources. Other partners are continuing to join the project as additional requirements and resources become available. The information presented below provides a summary of the major tasks and associated products that NOS anticipates from mapping the benthic habitats of the main 8 Hawaiian Islands.

When FY01 funding levels are known, this plan will be revised to show expenditures by task, institutional funding agreements, and task completion dates. In addition, based on the results of year 2000 and early 2001 remote sensing research, NOS will determine the exact suite of remote sensing technologies to be used in FY01/02 to map the main 8 Hawaiian Islands.

Approach:
Coral reef mapping studies in the main 8 Hawaiian Islands were initiated by NOS and its partners in April of 2000. This 3-month data collection effort resulted in 550 1:24,000 scale color aerial photographs acquired and converted to digital imagery. In addition, hyperspectral imagery (a camera which captures many wavelengths of light) was collected for about 1/3 of the near-coast coral reefs. The 2000 hyperspectral experiments were conducted to continue investigating the use of new technologies that may enable coral reef maps to be produced more accurate and efficient. Thus, a major goal of the Hawaii mapping program is to develop a standard set of protocols for benthic habitat mapping using a suite of technologies ranging from satellite, aircraft, and in-situ sampling platforms. Emphasis has been placed on airborne high resolution remote sensing tools to enable development of comprehensive benthic habitat maps for all US coral reef ecosystems within 5-7 years (see US CRFT Mapping Implementation Plan at http://biogeo.nos.noaa.gov/MIP/).

Digital photographs and/or complementary hyperspectral data will be obtained for the remaining 2/3 of the main 8 Hawaiian Islands over a 12-18 month period beginning in the fall of 2001. Data collection in 2001 will mimic collection efforts for year 2000 with the area from the shoreline to water depths of approximately 30 meters (the approximate limit of feature detection for digital photographs and hyperspectral data) studied. Visual interpretation using NOS derived software enables “heads-up” identification and delineation of 37 different habitat types found throughout Hawaii coral reef ecosystems. In addition, the complementary hyperspectral data set is under analysis with the University of Hawaii to determine if computer generated habitat maps can be derived from the unique “spectral signatures” (reflectance of light) of benthic habitats. This developing tool provides great promise to map coral reef ecosystems much more rapidly and using objective classification rules.

Tasks – The following Tasks are the major steps to be initiated in FY 01 to ensure completion of map products in FY03. In addition, please see the list of products in the last section to see planned outcomes and other tasks associated with mapping of the main 8 Hawaiian Islands.

Task 1: <u>Implement Contract to collect Digital Frame Camera Imagery for the Island of Ohau</u>.

Data will be processed and delivered to NOS and its partners for processing and interpretation. This effort will integrate data collected in FY01/02 by the US Dept .of Agriculture in Hawaii on land use and land cover characteristics. The intent of this task is to develop a prototype digital map product that links landuse activities to adjacent coral reef ecosystem in support of coastal zone management decisions. **(Products 4 months from award).**

Task 2: <u>Implement Contract to collect Hyperspectral Imagery for the main 8 Hawaiian Islands.</u>

Based on the results of NOS hyperspectral experiments conducted with the University of Hawaii, Analytical Lab. of Hawaii, and Advanced Power Tech. Inc., NOS will recommend the best approach for implementing the use of hyperspectral imagery in Hawaii. The Hawaii based contractors and APTI, Inc (hyperspectral contractor) are tentatively scheduled to report their finding to NOS on April 2, 2001. **(Data Collection 12-18 months from contract award).**

Task 3: <u>Implement contracts to visually interpret both the digital frame camera data and the hyperspectral imagery</u>.

Currently, the most accurate method to develop coral reef ecosystem maps for 37 levels of habitat classes is by visual image interpretation. As georeferenced data from both the digital frame camera and the hyperspectral imagery become available, this information will be interpreted to develop map products **(12 months).**

Task 4: <u>Field Accuracy Assessment and Validation</u>.

This task is comprised of two components: 1) field groundtruthing, and 2) field accuracy assessment. This Task will also include review of draft digital maps by the local community. The integrated steps are required to ensure map accuracy both in space and habitat characteristic and QA/QC of final digital map products. **(18 months).**

Task 5: <u>Hyperspectral Experiments.</u>

Because of the potential to automate portions of the coral mapping studies due to the high spectral resolution of hyperspectral imagery, NOS will continue to build upon the current NOS and University of Hawaii cooperative agreement to conduct a suite of experiments. A progress report on this work is due in May of 2001. Based on the results in this report, future efforts will be developed for 2001 and beyond. **(24 month cooperative agreement).**

Task 6: <u>Final Digital Benthic Habitat Maps for Selected Islands.</u>

NOS and its partners will develop and deliver final digital map products to the user community for portions of the main 8 Hawaiian islands in FY 02 and plans are to complete all of the digital maps in FY03. Task includes the development of a CD-rom and website to disseminate the benthic habitat

PLANNED PRODUCTS & OUTCOMES FOR MAPPING OF THE MAIN 8 HAWAIIAN ISLANDS IN FY 01/02

Available Now:

• Draft classified maps of coral reefs along the northwestern Kona Coast, Hawaii and Kaneohe Bay, Oahu. These maps 37 categories of habitats and are based on visual interpretation of digital color aerial photographs and hyperspectral imagery.

•A report summarizing the results of an accuracy assessment of visual interpretation of hyperspectral imagery for shallow-water coral reef mapping at selected sites in the eight main Hawaiian Islands.

•A georeferenced, orthorectified mosaic (circa 1990) of Hawaiian Islands from Landsat 4/5 multispectral satellite imagery.

• A georeferenced, orthorectified mosaic (circa 2000) of Hawaiian Islands from Landsat 7 multispectral satellite imagery.

• A peer-reviewed Coral Reef Ecosystem Habitat Classification scheme, which is required for consistent mapping and characterization of the habitats.

• Approximately 550 1:24,000 scale color aerial photographs covering approximately 500 kilometers (1/3) of the shoreline of the eight main Hawaiian Islands. These images are available as 500 dpi TIFF files on CD-ROM.

• Hyperspectral imagery covering approximately 500 kilometers (1/3) of the shoreline of the eight main Hawaiian Islands.

•A digital data set of over 700 site characterizations (groundtruthing data) of benthic habitats for Kanehoe Bay, Ohau and the Kona coastline of Hawaii.

•An ArcView GIS-based Habitat Digitizer Extension available for use on any PC operating ESRI ArcView software.

• Several multi-year contracts with Hawaii private companies and a cooperative agreement with the University of Hawaii to continue to develop mapping products.

Soon-to-be-Available (within 6 months):

• Draft classified maps of coral reefs along the Kihei Coast, Maui. This map will depict up to 37 categories of habitats and is based on visual interpretation of digital color aerial photographs and hyperspectral imagery.

• A report summarizing the results of an accuracy assessment of computer interpretation of high-resolution satellite and hyperspectral imagery for shallow-water coral reef mapping at selected sites in the eight main Hawaiian Islands.

• An integrated network of GPS- and tide-controlled monuments for the eight main Hawaiian Islands.

• A established datum and geoid for the eight main Hawaiian Islands.

• Available on the Web - a downloadable georeferenced, orthorectified mosaic (circa 1990) of eight main Hawaiian Islands from Landsat 4/5 satellite imagery.

• Available on the Web - a downloadable georeferenced, orthorectified mosaic (circa 2000) of eight main Hawaiian Islands from Landsat 7 satellite imagery.

• Classified Landsat satellite-based maps of land areas of the eight main Hawaiian Islands.

• A series of georeferenced AVIRIS moderate resolution hyperspectral imagery for portions of the eight main Hawaiian Islands (NASA and NOAA).

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Satellite Mapping of U.S. Coral Reef Ecosystems

Satellite imagery will be used support the integrated mapping and characterization of U.S. shallow-water coral reef ecosystems. Since 1999, NOAA has been collaborating with other federal agencies, especially NASA and USGS, and state and private organizations to produce, for the first time, comprehensive, accurate, georeferenced maps of all U.S. coral reef ecosystems. An estimated 17,000 square kilometers of coral reefs lie in U.S waters, with most of these in the Northwestern Hawaiian Islands. An unknown area of coral reefs are in the waters of the the freely associated states affiliated with the U.S., such as the Republic of Palau and the Federated States of Micronesia. The vastness, remoteness, and lack of information about both U.S. and other coral reef ecosystems will make their mapping a challenge.

The U.S. Coral Reef Task Force

Mapping U.S. coral reef ecosystems is one of four critical actions called for in the U.S. Coral Reef Task Force's National Action Plan to Conserve Coral Reefs. The U.S. Coral Reef Task Force, established by an Executive Order the President signed in June 1998, is charged with conserving, protecting, and restoring the Nation's coral reef ecosystems for future generations. The National Action Plan, released by the Task Force in March 2000, lays out a carefully considered, science-based road map to healthy coral reefs for generations to come. Additional actions described in the Plan include developing a nationally coordinated coral reef inventory, assessment, and monitoring program, and supporting strategic research focused on the determinants of coral reef health and recovery. Detailed maps will be important in undertaking these activities. Maps will be especially critical when conducting assessment and monitoring activities in remote locales where logistical difficulties limit access or when assessing changes in the ecosystem over time. Both airborne and satellite-based imaging technologies are being used to complete the U.S. coral reef mapping effort.

A long-term goal of the Plan is to assess global threats to coral ecosystems. A recent international assessment released in December 2000 by the Global Coral Reef Monitoring Network reports that a measurable decline in the extent and health of coral reefs worldwide has occurred over the last few years and clearly demonstrates the plight of these critical ecosystems. Once available, maps depicting the distribution of reefs worldwide will be invaluable in better assessing and understanding the causes of their decline.

Marine Protected Areas

Maps of coral reef ecosystems will be critical to designating and managing MPAs in the tropical U.S. In May 2000, an Executive Order was signed by the President to strengthen and expand the Nation's system of marine protected areas (MPAs). The purpose of the order is to: 1) strengthen the management, protection, and conservation of existing marine protected areas; 2) establish new or expanded MPAs; 3) develop a scientifically based, comprehensive national system of MPAs representing diverse U.S. marine ecosystems, and the Nation's natural and cultural resources; and 4) avoid causing harm to MPAs through federally conducted, approved, or funded activities.

Satellite imagery holds great promise for mapping U.S. and international coral reef ecosystems. However, producing comprehensive, accurate, georeferenced coral reef ecosystem maps is a challenging task. Waves, clouds, water turbidity, water depth, and sun glint affect the ability to see, much less identify, bottom features. While meteorological conditions cannot be controlled, minimizing sun glint by controlling the acquisition of imagery is a significant stride in technology provided by the IKONOS satellite. As a result, this technology becomes an important tool for conducting research and monitoring activities in these areas. Combined with its capacity to acquire high resolution imagery in remote locales where the deployment of aircraft-based imaging platforms is limited or nearly impossible, the IKONOS satellite may also prove to be a very practical tool for coral reef mapping.

Maps produced from the imagery will have numerous uses. For essentially the entire world, these maps will be the first accurate, georeferenced maps of coral ecosystems ever produced. They will provide a base line for future research and monitoring effort undertaken in these areas. The maps will provide critical information for Essential Fish Habitat and Habitat Suitability characterizations and management plans related to sustainable use of fisheries. These plans are called for under federal statutes such as the Magnuson-Stevens Fishery Conservation and Management Act. The maps will provide the base maps for long-term monitoring and change analysis of both nearby and remote coral reef ecosystems. The satellite imagery itself will, for nearly all of these areas, be used to produce the first ever bathymetric maps. Lastly, these maps can be incorporated into decision support tools to help answer management questions.

Both moderate-resolution Landsat and commercially available high-resolution satellite imagery has been ordered for a number of important areas in the Pacific. In particular, high-resolution imagery has been received for seven areas: 682 square kilometers of French Frigate Shoals; 515 square kilometers of Lisianski; 126 square kilometers of Kure Atoll; 141

square kilometers of Laysan Island, 494 square kilometers of Pearl and Hermes Atoll; 272 square kilometers of Necker Island; and 87 square kilometers of Gardner Pinnacles. Producing the maps will require: acquiring additional imagery; generating a cloud-free, georeferenced mosaic of the imagery for each locale; generating draft classified maps from the imagery; and planning and conducting field verification of the draft maps.

Products and Services

A suite of products and capabilities will be produced during each phase of the mapping effort. For example, in Phase 1, a set of hard copy and digital maps will be produced using the moderate resolution satellite imagery. Also, a custom web-based application may be developed to support the design of a mission to acquire ground control points throughout the Reserve. During the Phase 2 mapping with high resolution satellite imagery, there may be a need to develop a web site that provides access to degraded examples of the imagery. Also, custom web-based applications may be needed to support the characterization of the imagery or to support the establishment of a suite of long-term monitoring sites. All of these will be developed with input from federal and state coral reef mapping partners.

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A Plan to Map and Characterize the Coral Reef Ecosystems of the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve

The Goal

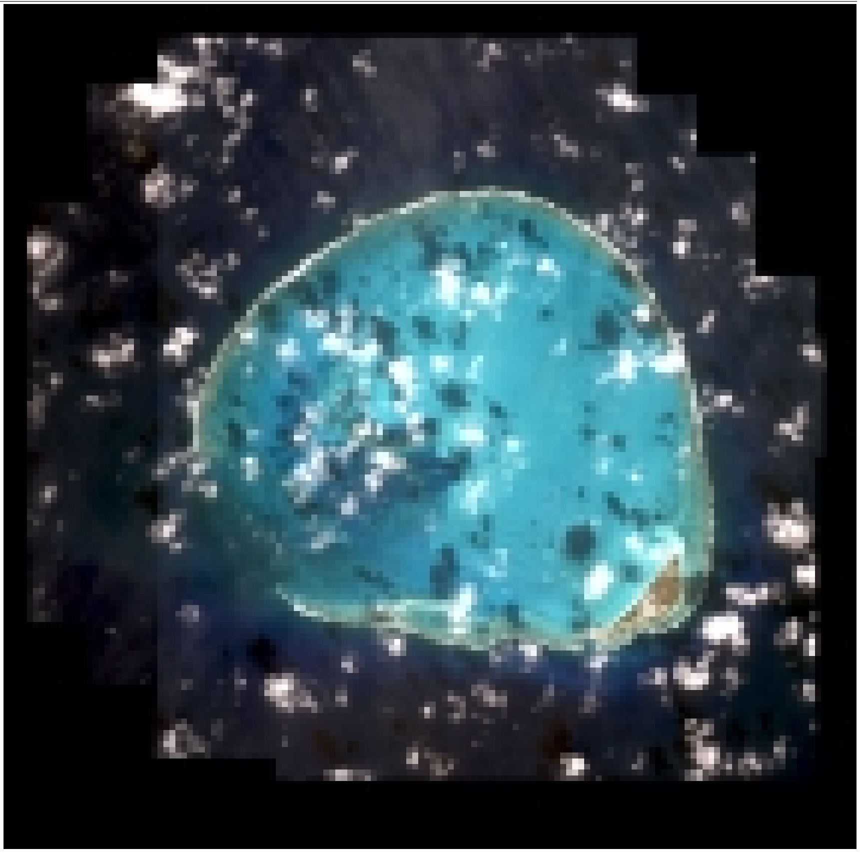
Produce, in five years, comprehensive digital coral reef ecosystem maps to facilitate the development and implementation of a management plan to conserve and protect the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve.

The Challenge

A plan will be developed for the cooperative management and conservation of the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (Reserve) by federal and state agencies in cooperation with local partners. The management strategies articulated in the plan - and their implementation - will rely heavily on the availability of comprehensive, georeferenced maps of the coral ecosystems in the Reserve. Other uses of the maps include characterizing essential marine organism habitat, monitoring the baseline condition of the reef ecosystems and factors affecting their condition, enforcing regulations on fishing and similar activities in the Reserve, and assessing the extent and impact of marine debris on the reefs. Finally, maps will be critical for assessing changes taking place in the reef ecosystems over time.

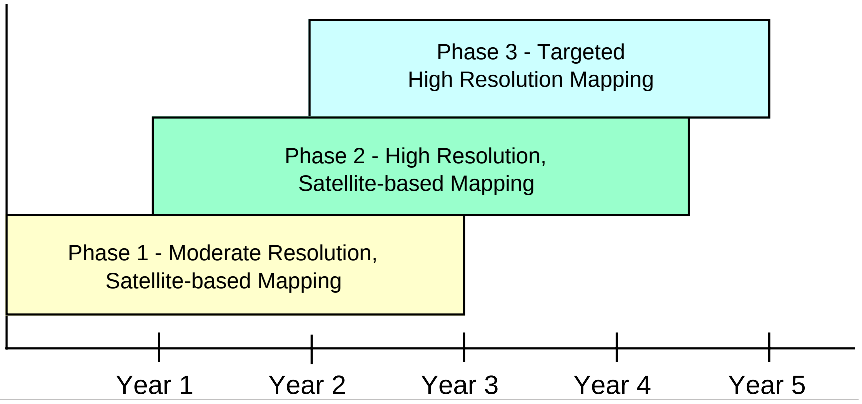
The Approach

Using a phased approach, maps of the Reserve with different spatial or spectral resolution will be produced (see Figure 1). In the first phase, maps derived primarily from moderate-resolution (30 meter multispectral) satellite imagery will be produced. Moderate-resolution Landsat satellite imagery has been acquired for the entire Reserve and procedures have been developed for deriving benthic habitat maps from the imagery. In phase 2, maps derived primarily from high-resolution (4 meter multispectral) satellite imagery will be produced. High-resolution, commercially-available satellite imagery has been obtained for four areas in the Reserve and has been ordered for five other areas. The phase 3 mapping effort will involve identifying and generating maps for targeted geographic areas in



An IKONOS satellite image of Kure Atoll.

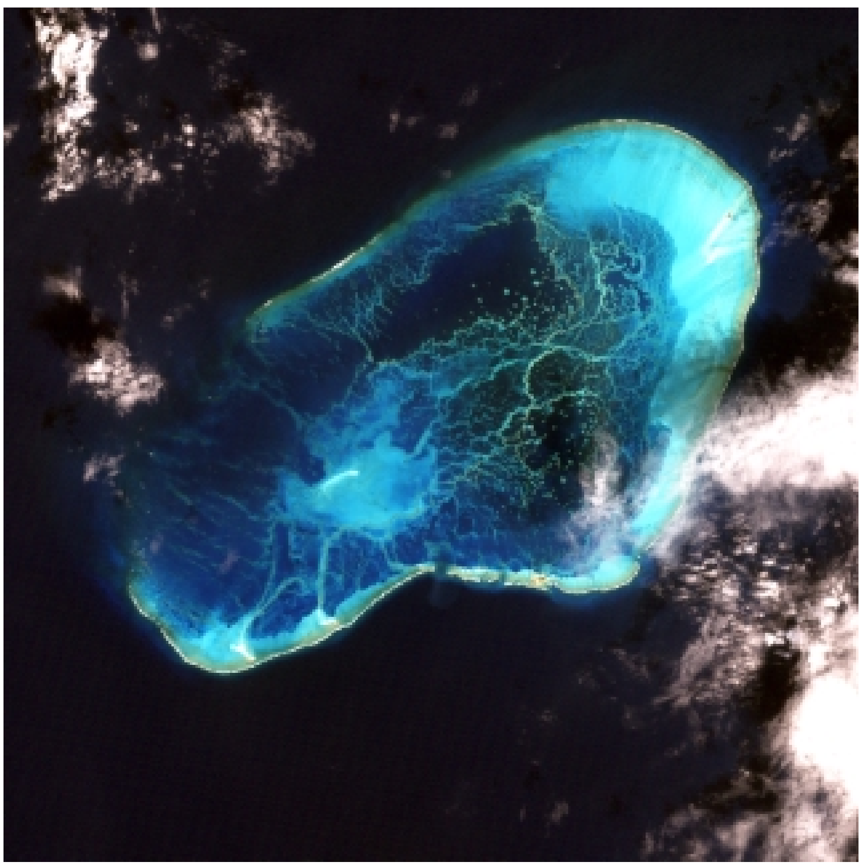
Figure 1. A five-year, three phase coral reef mapping effort in the Reserve.



the Reserve where very high spatial or spectral resolution is needed. Airborne aerial photography and/or hyperspectral imagery may be used in this phase.

Extensive coral reefs lie in Hawaiian state waters that are part of the Northwestern Hawaiian Islands, but not part of the Reserve. These reefs will be mapped simultaneously with the Reserve coral ecosystems.

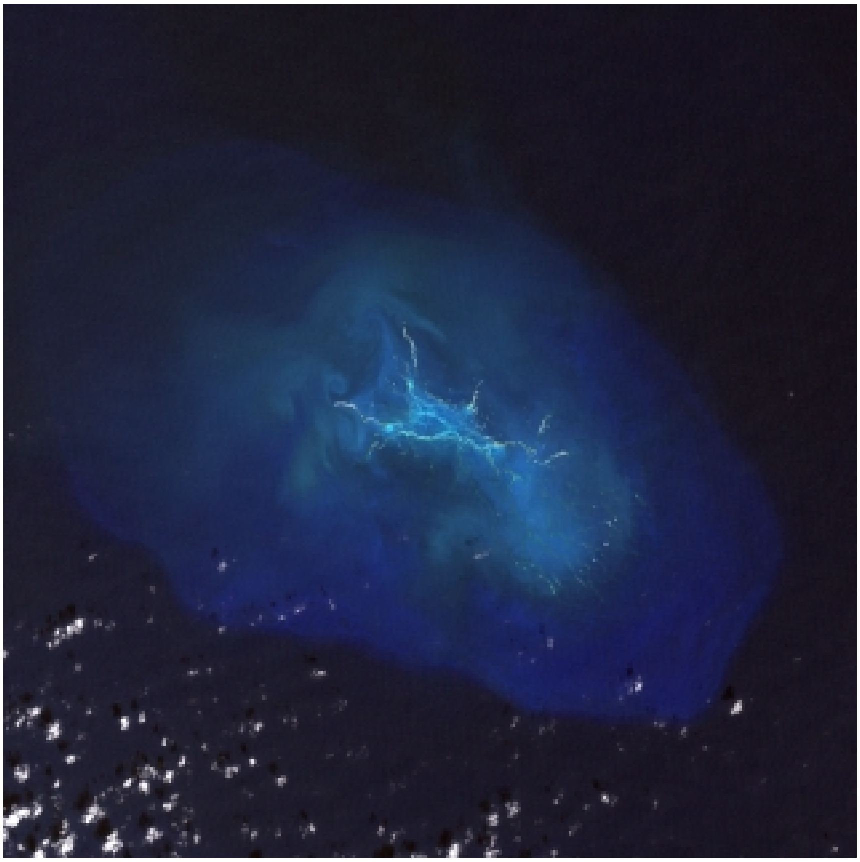
Some other activities have already started that will provide important information for all three phases of mapping. Detailed bathymetric data are critical for mapping and characterizing the Reserve's benthic habitats, and an effort is underway to compile all available bathymetric data for the Reserve. At this time, hydrographic information depicted on NOAA nautical charts may, however, be the best available data for the area. A plan is being developed by the Office of Coast Survey for acquiring high resolution LIDAR bathymetric data for shallow-water (0-30 meters) areas in the Reserve. Until the LIDAR data are available, the moderate and high rsolution imagery may be used to derive shallow water bathymetry where needed. Measuring bathymetry at depths greater than 30 meters will require other technologies, such as ship-based multibeam and backscatter and/or other side-scan sonar. Mapping benthic habitats with satellite and bathymetric data will require the acquisition of water-based accuracy assessment and land-based ground control points data. Some accuracy assessment points and ground control points have been acquired in the Reserve, but more will need to be gathered. A draft hierarchical marine habitat classification scheme is being developed for the eight main Hawaiian Islands. Building on this work and that of Holthus and Maragos (1995) and NOAA (1999), the scheme should be modified for classifying Reserve benthic habitats.



A Landsat 7 satellite image of Pearl and Hermes Atoll.

In the Fall of 2000, an extensive survey of marine and terrestrial environments was conducted at 10 Reserve locales as part of a joint State of Hawaii, Fish and Wildlife Service and NOAA activity. The results of that survey will provide valuable information as the Reserve's ecosystems are characterized. The survey results also will be important in assessing changes in the Reserve over time.

Several important activities should be initiated as soon as possible in the mapping effort. First, partners in the mapping process need to modify the peer-reviewed classification scheme for the eight main islands to include those benthic habitats found in the Reserve. Second, an assessment of the strengths and weaknesses of each imaging technology for generating adequate maps needs to be completed. Third, consensus needs to be reached on the priority of specific mapping tasks, such as ground control point or LIDAR acquisition. Fourth, cost estimates for producing and validating the maps need to be developed. Finally, consensus should be reached on the products to be generated as part of the mapping effort. For example, depending on the technology chosen, products can be produced containing: 1) digital imagery of areas; 2) digital image mosaics with classified habitats; and 3) GIS-based digital classified habitat maps. A mapping methods manual, with descriptions of procedures and benthic habitats, also will be produced



A Landsat 7 satellite image of Maro Reef.

Mapping and characterizing the coral reef ecosystems of the Reserve is, however, a challenging undertaking. These coral ecosystems are the most visible part of a string of islands, atolls, pinnacles, and seamounts extending over 2,000 kilometers WNW of Kauai. Only two aircraft landing strips exist in the Reserve. The first, on Tern Island at French Frigate Shoals, is about 750 kilometers from Kauai. The second, on Midway, is nearly 2,000 kilometers from Kauai. The landing strip at Tern Island is suitable for small planes only. In addition, the U.S. Fish and Wildlife Service restricts access because of the island's importance as a bird rookery. The landing strip at Midway accommodates commercial flights. Access by sea requires large vessels that can stay at sea for several days to weeks. There is no place for a ship to refuel within the entire Reserve. Provisions can be obtained only at Midway.

Regardless of the difficulties, these maps will be an important component of the effort to manage, conserve, and protect the Reserve. It is estimated that as much as 70 percent (11,900 square kilometers) of the coral reef ecosystems under direct U.S. protection lie in the Reserve. These reef areas are home to an estimated 7,000 species of organisms, including the endangered Hawaiian monk seal, the endangered Laysan teal and at least 19 other species of sea birds, the threatened green sea turtle, two endangered species of sea turtles, and three other turtle species, and thousands of species of fishes and invertebrates. Regardless of their scale, the maps will represent a fundamental component in the process of developing an integrated program for the characterization and long-term monitoring of benthic habitats in the Reserve.

Mapping Phases

In the first phase, maps derived primarily from moderate-resolution satellite imagery will be produced. These maps -representing the first georeferenced, classified maps of the Reserve, will depict the location of benthic habitats found in water generally less than 30 meters in depth. These maps will be crucial for the development of the Reserve Management Plan, as well as for the planning of future mapping and characterization activities. The imagery used to derive these maps also may be used to derive approximate shallow-water bathymetry for those areas where this information is lacking.

As noted earlier, some tasks associated with the Phase 1 mapping effort are already underway. Other steps in the Phase 1 mapping effort include: acquiring additional imagery; generating a cloud-free, georeferenced mosaic of the imagery for each locale; obtaining additional ground control and accuracy assessment points; completing a draft classification system; generating draft classified maps from the imagery; planning and conducting field verification of draft maps; and deriving estimated bathymetry from Landsat imagery where needed. Advantage will be taken of every opportunity to work with other federal and state agencies to acquire new imagery, hydrographic data, accuracy assessment and ground control points, and other information.

During the phase 2 mapping, maps derived primarily from high-resolution satellite imagery will be produced. These maps - representing the first high-resolution georeferenced, classified maps of the Reserve, also will depict the location of benthic habitats found in water generally less than 30 meters in depth. In addition, these maps - and the images from which they are derived - will provide researchers and resource managers with levels of detail previously available only from aerial photography. These maps will be important for developing essential habitat characterizations of coral reef organisms, assessing the extent and impact of marine debris, and as a baseline for characterizing possible changes in shallow-water benthic habitats over time. As shallow-water and deep-water (30+ meters deep) bathymetry data are acquired, these data will be incorporated into the mapping effort.

High-resolution satellite imagery has been ordered for nine critical Reserve areas. To date, high-resolution imagery has been received for seven of these nine areas: 682 square kilometers of French Frigate Shoals; 515 square kilometers of Lisianski; 126 square kilometers of Kure Atoll; 141 square kilometers of Laysan Island, 494 square kilometers of Pearl and Hermes Atoll; 272 square kilometers of Necker Island; and 87 square kilometers of Gardner Pinnacles. As in the Phase 1 effort, producing the maps will require: acquiring additional imagery; generating a cloud-free, georeferenced mosaic of the imagery for each locale; generating draft classified maps from the imagery; and planning and conducting field verification of the draft maps. As in Phase 1, advantage will be taken of every opportunity to partner with other federal and state agencies to acquire additional imagery, hydrographic data, accuracy assessment and ground control points, and other information.

The phase 3 mapping will involve generating maps for targeted specific geographic areas in the Reserve where very high spatial or spectral resolution maps are needed. Where these more detailed characterizations of shallow-water (0-30 meter) benthic habitats are needed, activities will be initiated to generate maps derived from aerial photography and/or airborne hyperspectral imagers. These targeted efforts can be used to evaluate the distribution of certain benthic habitats based on their spectral signature or their size. Because, at this time, the imagery needed for these types of detailed maps requires instruments deployeed on aircraft platforms, only targeted activities and studies will be undertaken. Fortunately, the phase three mapping activities will benefit from the knowledge and data acquired during the phase one and two mapping efforts.

Products and Services

A suite of products and capabilities will be produced during each phase of the mapping effort. For example, in Phase 1, a set of hard copy and digital maps will be produced using the moderate resolution satellite imagery. Also, a custom web-based application may be developed to support the design of a mission to acquire ground control points throughout the Reserve. During the Phase 2 mapping with high resolution satellite imagery, there may be a need to develop a web site that provides access to degraded examples of the imagery. Also, custom web-based applications may be needed to support the characterization of the imagery or to support the establishment of a suite of long-term monitoring sites. All of these will be developed with input from federal and state coral reef mapping partners.

Coral Reef Task Force

Mapping the coral reefs of the Reserve is part of a larger effort to map all U.S. coral reef ecosystems by the U.S. Coral Reef Task Force. The Task Force, established by President Clinton through an Executive Order, is to lead both domestic and international efforts to protect, restore, and sustainably use U.S. coral reef ecosystems. In March 2000, the Task Force released its National Action Plan to Conserve Coral Reefs. The National Action Plan identifies four activities for conserving the reefs, one of which is developing comprehensive maps of all U.S. coral reefs. This plan to map the Northwestern Hawaiian Islands Reserve coral reefs has been developed in coordination with the Task Force's larger national mapping activity. Other activities, such as evaluating the condition of Reserve coral reefs, will be coordinated with similar Task Force efforts.

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Tasks and Budget for Mapping shallow-water Northwestern Hawaiian Islands coral reef areas.

Federal and state agencies need to coordinate in mapping an characterizing the coral reef ecosystems of the Northwestern Hawaiian Islands. There are numerous opportunities to partner on activities or perform in-kind activities that benefit partners. For example, there is a need to establish tide-controlled bench marks and GPS monuments on large land areas in the Reserve (actually, Hawaiian land). Tide-control is required for shallow- and deep-water bathymetric data acquisition. Also, an effort to gather habitat accuracy or validation point data would benefit both the monitoring and mapping activities. This shallow-water mapping activities (and the imagery used in the process) will result in maps of mostly Hawaiian state waters. Little of the NWHI Coral Reef Ecosystem Reserve's reefs are in shallow (<20 fathoms) water. Reserve Preservation Area water (>20 fathoms/outside 3 nm - 100 fathoms) will require ship-based hydrographic mapping and subsequent in-situ characterization.

Tasks to be completed over the next 6 months:

1. Generate DRAFT CORAL REEF MAPS FOR 2-3 LOCALES in the NWHI. The need exists to demonstrate that classified maps of NWHI coral reefs can be produced. We already have high-resolution, essentially cloud-free satellite imagery for several NWHI locales. As soon as possible, we will generate un-validated maps of the coral reefs of 2-3 locales (Pearl and Hermes Atoll, Kure Atoll, and one other location 1 in NWHI).

2. ORDER/ACQUIRE IMAGERY: Acquire additional IKONOS imagery to map shallow-water areas (essentially 0 - 20 fathoms) in the NWHI.

Location	current area (sq. kms.)	new area (sq. kms.)	new area est. cost ($)
Pearl and Hermes Atoll	494	520	$15,600.00
French Frigate Shoals	682	725	$21,750.00
Kure Atoll	126	126	$3,780.00
Gardner Pinnacles	87	250	$7,500.00
Nihoa Island	158	?	$4,740.00
Necker Island	272	?	$8,160.00
Midway Islands	155	?	$4,650.00
Laysan Island	141	?	$4,230.00
Lisianski Island	516	?	$15,480.00
Maro Reef	601	?	$18,030.00
		sub TOTAL	$103,920.00

3. Assess Imagery POSITIONAL ACCURACY: Establish the positional accuracy of IKONOS imagery with and without additional GCPs. We will purchase both archive and new IKONOS imagery for locales already evaluated or to be evaluated by NGS for positional accuracy. We will work directly with NGS to write a summary document on positional accuracy of IKONOS and specifications for GCP requirements to increase positional accuracy.

Location	area (sq. kms.)	area est. cost ($)
San Diego, CA (archive)	120	$2,400.00
Houston/Galveston, TX (archive)	120	$2,400.00
Seattle, WA (archive)	120	$2,400.00
Tacoma, WA (archive)	120	$2,400.00
Location 1 (new)	100	$3,000.00
Location 2 (new)	125	$3,750.00
Location 3 (new)	100	$3,000.00
Location 4 (new)	100	$3,000.00
	sub TOTAL	$19,950.00

4. Develop a CLASSIFICATION SCHEME for the NWHI: Working with NWHI coral partners, establish a benthic classification scheme suitable for use with satellite imagery, as well as for other technologies. A hierarchical coral reef ecosystem habitat classification scheme will need to be produced that recognizes the spatial and spectral strengths and weaknesses of IKONOS imagery. Several classification schemes have already been proposed for certain areas in the Pacific. These schemes will be evaluated in the context of their applicability to the satellite imagery and overall mapping goals. Classification will allow for semi-automated classification (at a few classes),for monitoring, as well as for visual interpretation with field data.

Conduct two workshops in Hawaii to develop and finalize NWHI Coral Reef Ecosystem Classification Scheme. $30,000.00

5. Establish GPS MONUMENTS and TIDE-CONTROLLED benchmarks on large land areas in the NWHI. Knowing where the land areas of the NWHI are is critical for better georeferencing images. These monuments are required for LIDAR and multibeam hydrographic surveys. We need to identify partners (NMFS, FWS, DLNR, USGS, University of Hawaii) to support the establishment of the sites. We'll need berths on a ship. $50,000.00

Tasks to be completed over the next 6 - 18 months:

6. Generate CLOUD-FREE mosaics of locales: Develop methods to create cloud-free images/maps from imagery (complete method development with examples in 2001). We will purchase both archive and new IKONOS imagery for locales where several "sets" of IKONOS scenes are available. Eliminating the clouds and cloud shadows involves using the water reflectance to identify and remove the cloud and cloud-shadow portions of the image, "filling in" the resulting holes with portions of additional images, and radiometrically adjusting the resulting image mosaic need to be developed. This activity will eventually be conducted by a contractor.

Location	area (sq. kms.)	area est. cost ($)
Kaneohe Bay, HI (archive)	100	$12,000.00
Wake Atoll (archive)	50	$12,000.00
Location 1 NWHI (new and archive)	400	$8,000.00
	sub TOTAL	$32,000.00
Develop task order contract to generate cloud-free mosaics of specific locales.		$75,000.00

7. Generate PSEUDO-BATHYMETRY from IKONOS imagery: Adapt and test existing optical mathematical algorithms for generating pseudo-bathymetry from the IKONOS imagery. We will work with HSD to obtain the best available bathymetry for several test areas to improve existing algorithms. The resulting procedures and algorithms will be critical for mapping all coral reef areas, especially those where NO bathymetry data area available. The accuracy of coral reef maps will greatly improve by being able to "eliminate" the distortion, diffraction, and diffusion caused by water column from the image water reflectance. We eventually will want a contractor to perform this work, once procedures are developed. We will start with five locales where we have either HSD survey data, LIDAR, or both (Kona and Kihei).

Location	area (sq. kms.)
Kona Coast, HI	302
Kihei, Maui	260
Kure Atoll, NWHI	126
Pearl and Hermes Atoll, NWHI	494
Midway Islands, NWHI (once imagery arrives)	155

Develop task order contract to generate pseudo-bathymetry of specific locales. $75,000.00

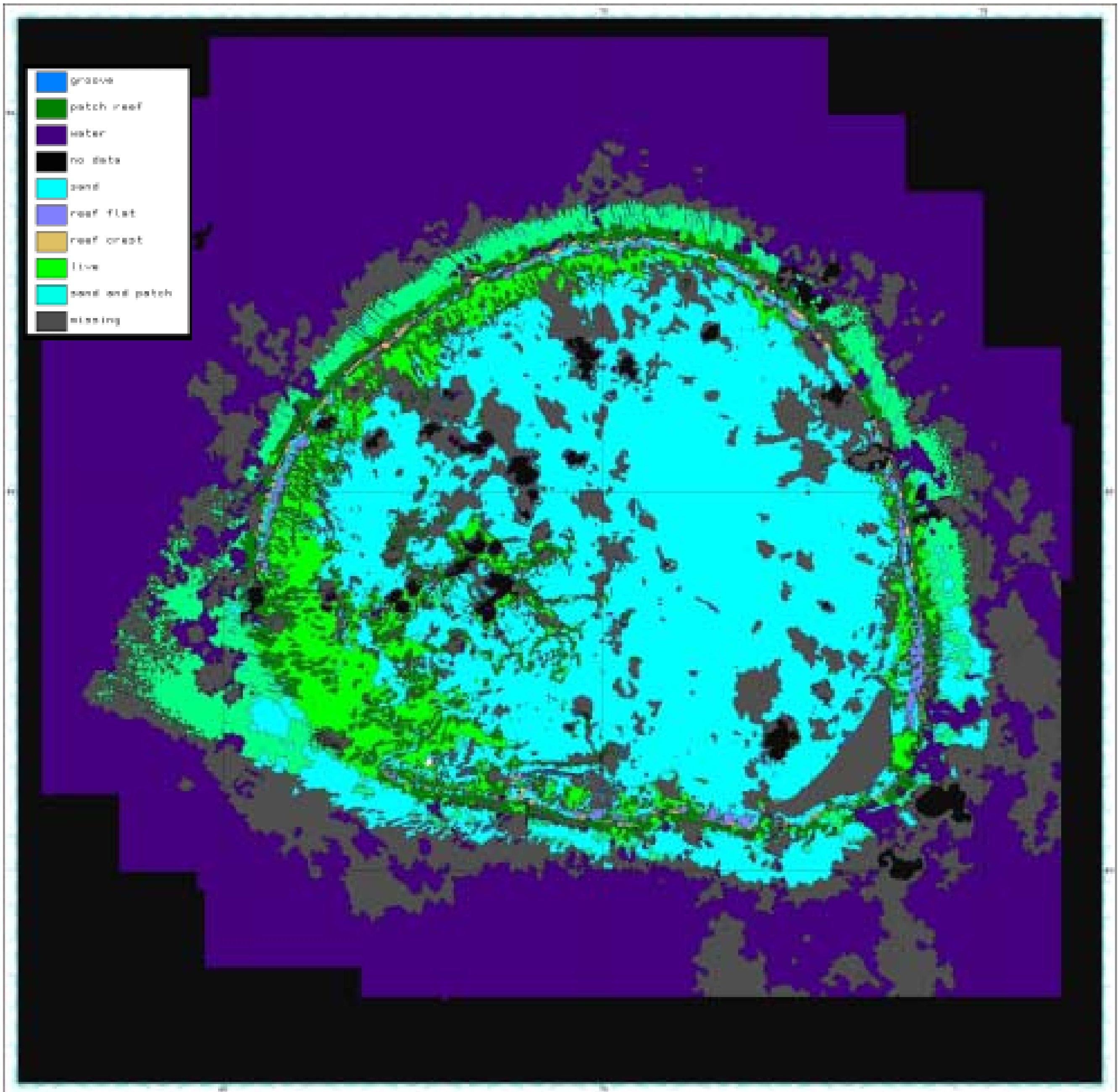
8. Establish procedures for PROCESSING IMAGERY: As it arrives at NOS, imagery will start a process leading to images and DRAFT maps of NW Hawaii. Whether processed in-house or by a contractor, entire process will be tracked. Where identified in process, NOS will provide supplemental data, such as bathymetry, DEMs, DOQs, etc. that support map production. Ultimately, a contractor will be used to complete most of the processing steps.

Develop a contract to test image processing procedures for specific locales. $75,000.00

9. Gather ACCURACY AND VALIDATION POINT DATA for a stratified sample of locations at each Reserve. Much of the effort will focus on shallow-water Hawaiian state waters. Logistical difficulties make gathering deep-water data problematic. We will need to work with partners (FWS, DLNR and others to gather the shallow-water data. We will need to work with other partners to start scoping out where to conduct deep-water surveys. We'll need berths on a ship for this effort too. We can start with Midway, Kure Atoll, and Pearl and Hermes, which are relatively easy to reach from Midway. $50,000.00

TOTAL Estimated COST $511,000.00

Draft Coral Reef Ecosystem Map Derived from Satellite Imagery: A preliminary classified benthic habitat map for Kure Atoll, Northwestern Hawaiian Islands, showing the distribution of sand, coral, and other bottom types. Some clouds and cloud shadows are present and will be removed with additional analysis. A final classified map will be developed after field validation in conjunction with the State of Hawaii, University of Hawaii, U.S. Fish and Wildlife Service, and other experts. Contact: Dr. Richard P. Stumpf, NOS Science Office, Center for Monitoring and Assessment.



Kure Island, NWHI, Preliminary Benthic Habitat Classification

Draft Bathymetry Map Derived from Satellite Imagery: Shallow-water bathymetry is being generated using the high-resolution satellite imagery and computerized image analysis. An example of preliminary bathymetry for Kure Atoll in the Northwestern Hawaiian Islands is shown. Hydrographic survey information for Kure is limited. For many other areas, such data do not exist. Analyzing the spectral signatures of the high-resolution satellite imagery provides reliable depths from 1 foot to at least 80 feet. As important, the high-resolution imagery can be geopositoned to within 60 feet of its location on the earth. Contact: Dr. Richard P. Stumpf, NOS Science Office, Center for Monitoring and Assessment.